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TUNDRA DISTURBANCE STUDY:
BURWASH UPLANDS, YUKON TERRITORY

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Tundra Disturbance Study: Burwash Uplands, Yukon Territory" submitted by Jackson Loré in partial fulfilment of the requirements for the degree of Master of Science

ABSTRACT

In the late 1800s a pack trail and wagon road was established from Burwash Landing, on Kluane Lake, Yukon Territory, northwestward to Canyon City near the Alaska border. On the Burwash Uplands the trail crosses an area of sedge tundra underlain by high ice-content permafrost. Disturbance of the organic layer has generated thermomelioration which has resulted in thermokarst subsidence and formation of complex microrelief. A favorable ground thermal regime and thick active layer has allowed the climax sedge association to be replaced by a more diverse shrub community. Certain wildlife populations use productive birch-willow stands along the trail. In turn, their activities cause a continuing disturbance which helps maintain the vegetation in a disclimax stage of succession. The highly irregular microrelief and shrub vegetation causes the accumulation of a greater snow cover than in the surrounding sedge tundra. An ameliorated subnivean environment creates a beneficial winter habitat for small mammal populations.

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CHAPTER I

INTRODUCTION

1.1 Introduction

In the historic past use of the biological resources of the North by native peoples had little detrimental effect on tundra ecosystems.* Native man in the North, although a dynamic factor in certain parts of the tundra, used the relatively small annual biological production to only a minor extent.

In recent years expanding activity in the North, especially that associated with gas and oil exploration, has caused increasing disturbance to the tundra biome. Many recent studies have focused on the initial effects of these disturbances, particularly those caused by roads and seismic lines. Many questions remain to be answered, however, before there will be an adequate understanding of the long term consequences of man's impact on tundra ecosystems.

1.2 Tundra Disturbance: An Environmental and Ecological Perspective

All development will alter terrestrial environments

---

*The actual impact of native man on tundra ecosystems is difficult to assess. Some investigators feel that early man was responsible at least in part for the extinction of certain mammal species (e.g., *Mammuthus primigenius*) (Flint 1970).

to some extent. In the North this alternation may have substantial ramifications on both the physical and biological components due to the fragility and instability of the arctic terrain.*

Studies (Mackay 1970; Radforth 1971; Bliss and Wein 1971, 1972; Heginbottom 1972; and Kerfoot 1972a, b) have shown that certain areas in the North American arctic tundra are especially sensitive to surface disturbance because of high ice-content permafrost. The most noticeable effect of any disturbance in areas of ice-rich permafrost is the topographic expression of that disturbance. In areas underlain by fine-grained sediments surface disturbance will generate thermomelioration of the active layer and subsequent loss of volume due to melting of ground ice; subsidence and/or erosion will occur (Mackay 1970, Kerfoot 1972a, b).

Mackay (1970, p. 420) also demonstrated the necessity of distinguishing the functional processes in thermal erosion and thermokarst subsidence and their relative importance:

> Thermokarst is derived from karst, a term used in geomorphology to describe certain features in limestone areas. Thermokarst is then "Thermal solution" or more precisely "thermal melting"; loss of water then results in thermokarst subsidence, or a thermokarst thaw lake, etc. Thermal melting depends upon heat conduction, for example from a pool of water directly overlying icy soil, or from conduction through an intervening layer of unfrozen soil. Therefore, unlike thermal erosion, no flowing water is required.

---

*Dunbar (1973) conceded that the naturally oscillating environment of the North requires a redefinition of the terms 'fragility' and 'instability' which recognizes the "ability of the system to adjust to perturbation . . . ."

He established that thermokarst subsidence resulting from thermal melting is the dominant consequence of man-induced disturbances in tundra areas underlain by high ice-content permafrost.

The significance of permafrost in surface disturbance is considerably dependent on the character of the soil active layer where most heat and moisture movements take place (Brown 1971). The nature of the active layer is in turn modified by a number of physical and biological elements of the tundra environment.

Climatic parameters such as absorbed solar radiation, wind, precipitation (particularly snow), and other components of the ground-atmosphere heat exchange are regionally and locally important for consideration in active layer studies. Gold and Lachenbruch (1973, p. 5) expressed the multiplicity of factors influencing the surface heat balance:

> The relative values of the components of the heat balance are quite sensitive to the characteristics of the surface, particularly albedo, availability of moisture, and type and extent of cover.

Brown (1970, 1973) pointed out that terrain relationships are primarily responsible for local variations in active layer thicknesses.

The relative importance of vegetation cover to the ground thermal regime and the dynamic interaction between intensive frost action and biological processes have been well documented in the literature (Hopkins and Sigafoos 1951; Benninghoff 1952; Tyrtikov 1959; Brown 1965; Johnson 1965;

Bliss 1970; Price 1971; Raup 1971; and others). In general any plant cover will retard the warming of the soil in summer and impede the cooling of the soil in winter, although the operative mechanisms and significance of different community types are not as yet fully defined. Tyrtikov (1959, p. 10) emphasized the influence of vegetation and organic matter on the ground heat budget:

> Under the vegetation cover the depth of thaw is usually 1.5-3 times less and the summer mean monthly temperatures at a depth of 15-40 cm are 5-15°C lower than where the vegetation is destroyed and the peat horizon (litter) is mineralized.

Initially, disruption of the plant cover will usually culminate in thermal modification of the soil and degradation of the permafrost. The extent depends largely on the type of plant cover, soil textural characteristics, albedo, and intensity of the disturbance (Brown 1966; Mackay 1970).

1.3 Research Objectives and Justification

Through a review of the relevant literature it becomes apparent that there are large gaps in the knowledge of various aspects of permafrost-vegetation-wildlife relationships. Despite the myriad of active layer measurements reported in the literature the causal relationships (in thaw depth) from one cover type to another are inadequately understood. The cumulative effect of landscape alterations proliferated by resource development and intensified through thermokarst activity is 'terra incognita'. Wildlife productivity is largely dependent on the type and availability of

habitat. Few studies have attempted to isolate the long term consequences of man-induced disturbances of wildlife habitats in arctic or alpine tundra environments. Thus, there is a need to define habitat requirements and the function of perturbation in these habitats. Scientists are beginning to recognize the validity and usefulness of the holistic 'landscape ecosystem' approach (cf. Rowe 1969) to northern environmental problems. It is the aim of this study to follow such an approach.

The intent of the present study is to examine the long term physical and biological consequences of a specialized type of disturbance in the alpine tundra of the Burwash Uplands, Yukon Territory, and to document the permanency of man's impact on this environment. Research objectives include: 1) determination of the extent and type of permafrost degradation (thermokarst activity) through analysis of microtopographic alterations and active layer development; 2) investigation of edaphic modifications associated with microtopographic and biological changes on disturbed sites; 3) classification and analysis of plant communities to determine the influence of perturbation on species diversity, abundance, and productivity; 4) observations of plant-animal relationships, including habitat modification and utilization; 5) examination of the ecological consequences of snow distribution on disturbed sites.

The Burwash Uplands was chosen as the area of study

for three reasons: first, previous tundra studies (Babb 1972; Hernandez 1972) investigated secondary plant succession following man-induced disturbances only at a pioneer stage, a few years after re-colonization. The Burwash Uplands study area offers an opportunity to examine a tundra environment that has been disturbed over a long period of time and on which vegetation has long since re-established. Second, a major intent of the study is to assess the effect of perturbation on wildlife habitats. In the study area one of the few remaining herds of the so called "giant mountain caribou" (*Rangifer tarandus osborni*) (Scotter *et al.* 1971) use this man-modified habitat at certain times of the year.* Recently, concern has been expressed for their continued survival (Theberge, undated). Last, with the recent establishment of Kluane National Park and in view of the accessibility of the Burwash Uplands,** this area will once again be under pressure from man's activities, thus information is needed on the physical and biological sensitivity of this alpine tundra ecosystem.

1.4 The Study Area

The Burwash Uplands was first described by Young

---

*Banfield (1960, p. 132) stated: "The Kluane Game Sanctuary seems to be one of the last strongholds of the Osborn mountain caribou in the Yukon." The taxonomic status of these caribou is in doubt. Oosenburg (personal communication, 1974) suggests that these caribou may in fact be related to the Alaskan sub-species *Rangifer tarandus granti*.

**The Burwash Uplands is adjacent to, but outside of, Kluane National Park (Figure 1).

(1947, p. 145):

> A great expanse of high barren country lay before us with hardly a tree in sight. In the distance it appeared to be quite smooth . . . .

1.4.1 Regional Location

The Burwash Uplands, approximately 80 km^2 of alpine tundra, is located 13 km west of Burwash Landing in southwest Yukon Territory (Figure 1). It ranges in elevation from 1000-1670 m (3000-5000 ft), although most of the upland area is at a height of 1330-1500 m (4000-4500 ft) (Figure 2). For the purpose of this study the Burwash Uplands is classed as a distinct regional unit based on topography and vegetation. It is defined as the alpine area lying between Burwash Creek on the north, Amphitheatre Mountain and Badlands Creek on the south, the Burwash-Wade Creek drainage divide on the west, and Duke River on the east (Figure 2).

1.4.2 Topography and Drainage

The Burwash Uplands is an upland, plateau-like extension of the physiographic subdivision known as the Duke Depression (Bostock 1948). The expanse of flat to broadly undulating topography contrasts markedly with the surrounding mountainous terrain of the rugged Kluane and Donjek Ranges, the latter which rise to an elevation of 3080 m (Plate 1). The most conspicuous relief feature on the Burwash Uplands is a broad elliptical granitic boss which projects 100-250 m above the general topography.

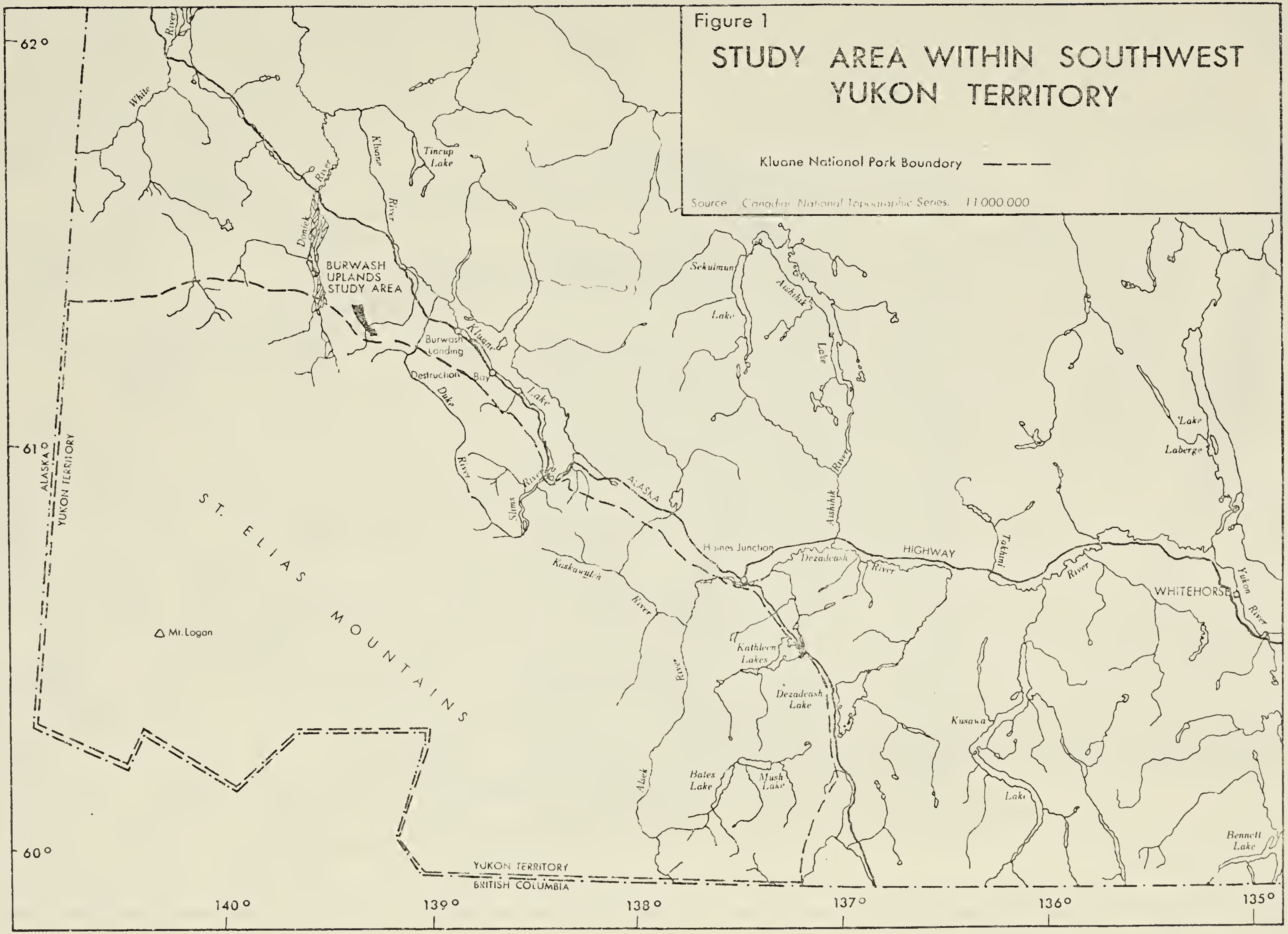


Figure 1

STUDY AREA WITHIN SOUTHWEST YUKON TERRITORY

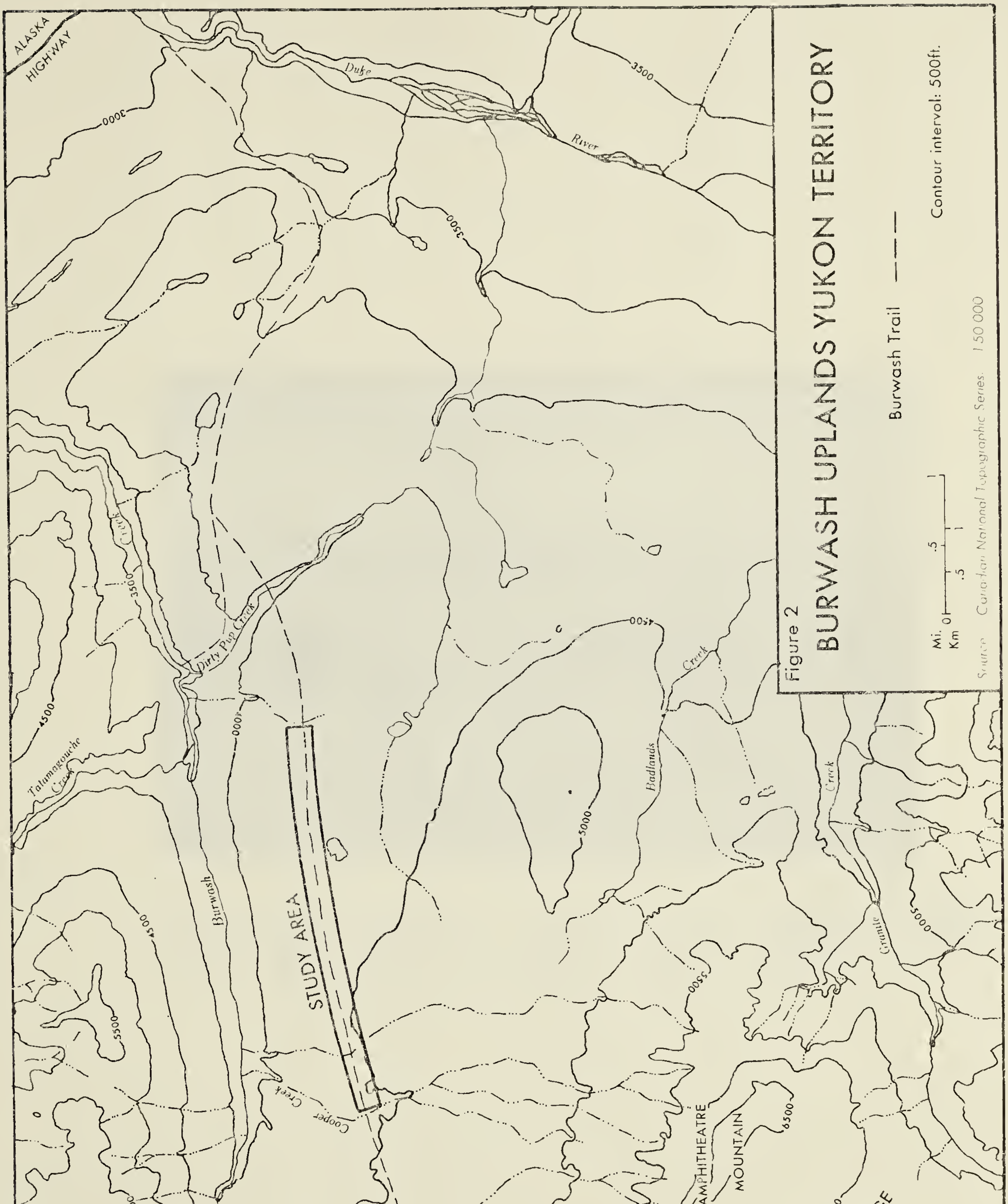


Figure 2
BURWASH UPLANDS YUKON TERRITORY

Plate 1. View northeast from Amphitheatre Mountain across the Burwash Uplands. Burwash Creek separates this plateau-like area of alpine tundra from the rugged Kluane Ranges in the distant center-left.

The presence of numerous small ponds and surface water attests to the general lack of an integrated drainage system over much of the study area. A thick organic mat, gentle gradients, and the occurrence of permafrost inhibits surface runoff and subsurface drainage, sustaining hygric conditions over much of the upland area.

1.4.3 Climate

The climate of the area is similar to the regional climate of the southwest Yukon Territory as modified by elevation and topography. A major feature of the regional climate is the presence of the St. Elias Mountains which range up to 6050 m in elevation and form an effective barrier against oceanic influences. Thus despite its proximity to the coast the area experiences a continental climate with long cold winters and short relatively mild summers (Kendrew and Kerr 1955). Because the area is situated in the lee of high mountain ranges, precipitation is generally light but highly variable due to orographic effects of the surrounding mountainous topography.

There is a distinct summer maximum of precipitation induced largely by radiative heating of the continental air mass which results in convective cloud formation and precipitation. The proximity of Kluane Lake (ca. 13 km) somewhat influences the summer precipitation patterns during easterly winds (Taylor-Barge 1969).

There is a paucity of information on the winter climate of the St. Elias Mountain region. The presence of the Mackenzie high is an important element of the winter synoptic pattern which produces cold, stable, continental-polar air masses. Maritime air, however, does penetrate the mountain barrier from time to time during the winter months (Taylor-Barge 1969).

Climatic data for Burwash Landing, 13 km east of the study area, are presented in Table I. It should be noted, however, that these have somewhat limited applicability to the study area because of elevational differences (ca. 500 m). but they do give a general indication of the climate in this part of the Yukon Territory.

1.4.4 Glaciation

Extensive glaciological investigations have been carried out northwest of the study area near Snag (Krinsley 1965; Rampton 1971) and at the southern end of the Kluane Lake (Denton and Stuiver 1967). However, the glacial history of the Burwash Uplands has escaped adequate investigation.

The surficial geology of the Burwash Uplands has been described only by Muller (1967). His brief interpretation proposes that the Uplands represents a remnant valley surface that resulted from a glacial advance termed the Nisling glaciation. This advance, the oldest known glaciation in the southwest Yukon Territory, extended up to an elevation

Table I

Climatic summary for the years 1967-72; Burwash Landing,

Yukon Territory Lat. 61° 21' N., Long. 139° 03' W.,

Elev. 801 meters a.s.l.*
(Degrees Celsius)

	Jan.	Feb.	March	April	May	June
Mean Daily Maximum	-21.4	-10.2	- 3.9	3.3	11.3	18.1
Mean Daily Minimum	-34.1	-25.1	-20.3	-10.1	- 1.8	3.2
Mean Daily Temperature	-27.8	-17.2	-12.1	- 3.3	4.8	10.7
Maximum Temperature Recorded	- 2.2	3.8	6.0	9.1	18.7	25.0
Minimum Temperature Recorded	-49.4	-43.1	-38.6	-22.7	- 9.7	- 2.9
Snowfall (mm)	22.1	6.6	14.7	20.8	11.0	---
Total Precipitation (mm)	10.7	5.1	12.7	20.3	20.3	35.6

	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Daily Maximum	18.4	16.4	10.2	2.1	- 7.6	-14.7
Mean Daily Minimum	5.3	3.4	- 1.4	- 9.4	-18.9	-27.8
Mean Daily Temperature	11.8	9.9	4.4	3.7	-13.1	-21.2
Maximum Temperature Recorded	24.6	22.5	16.7	11.2	6.8	3.4
Minimum Temperature Recorded	- 1.7	- 4.4	- 9.7	-22.0	-34.9	-43.5
Snowfall (mm)	---	1.8	6.4	13.2	16.8	16.0
Total Precipitation (mm)	63.5	25.4	27.9	12.7	15.2	15.2

*Climatic records commenced in Sept. 1966.

SOURCE: Canada, Dept. of Transport, Met. Branch, Monthly Record, Meteorological Observations in Canada, Toronto.

of 1830 m over the northeastern St. Elias Mountains.

Muller (1967) suggests a pre-Wisconsin age for the Nisling advance. A number of large granitic erratics on the Uplands suggests a source area either to the southwest in the Icefield Ranges and/or to the southeast in the Coast Ranges; in view of the present information it is likely that both were source regions.

A subsequent advance, known as the Ruby glaciation (early Wisconsin, Muller 1967), deposited a thick sequence of glaciofluvial and glaciolacustrine deposits. These are overlain by till which is currently being incised by the rapid headward erosion of a number of small Burwash Creek tributary streams that drain the Uplands. During a reconnaissance of exposures along "Dirty Pup Creek" (Figure 2) I estimated that the surficial deposits in this area vary from 10-100 m in thickness.

Rampton (1971) disagrees with Muller's (1967) interpretation and maintains that the Nisling glacial limit has been poorly delineated. He submits that Muller's Nisling advance, in the Kluane Plateau (east of the study area), corresponds with his Mirror Creek glaciation (Snag-Klutlan area). However, south of the Shakwak Valley (thus within the study area) the Nisling glacial limit has been outlined "far above the maximum limit of the Mirror Creek glaciation" (Rampton 1971). He cites an early Wisconsin age for the Mirror Creek glaciation in the Snag-Klutlan area.

Rampton (1971) further contends that the Ruby advance is the correlative of his Macauley glaciation which has been dated at ca. 40,000-13,500 B.P. or mid to late Wisconsin.

1.4.5 Permafrost and Periglacial Features

Permafrost is continuous throughout the Burwash Uplands. Based on regional permafrost studies conducted in the southwest Yukon Territory and Alaska (Brown 1967; Brown and Péwé 1973), I estimate permafrost depth to be between 30-60 m. In the undisturbed portion of the sedge tussock tundra, the active layer generally ranges from 30-40 cm, depending on thickness of the organic cover, topography, and aspect.

Frost features observed on the Burwash Uplands are similar to those described by Hopkins and Sigafoos (1951) for the Seward Peninsula, Alaska. Low-centered polygons, hummocks, and frost boils are the predominant periglacial landforms on the poorly drained upland area.

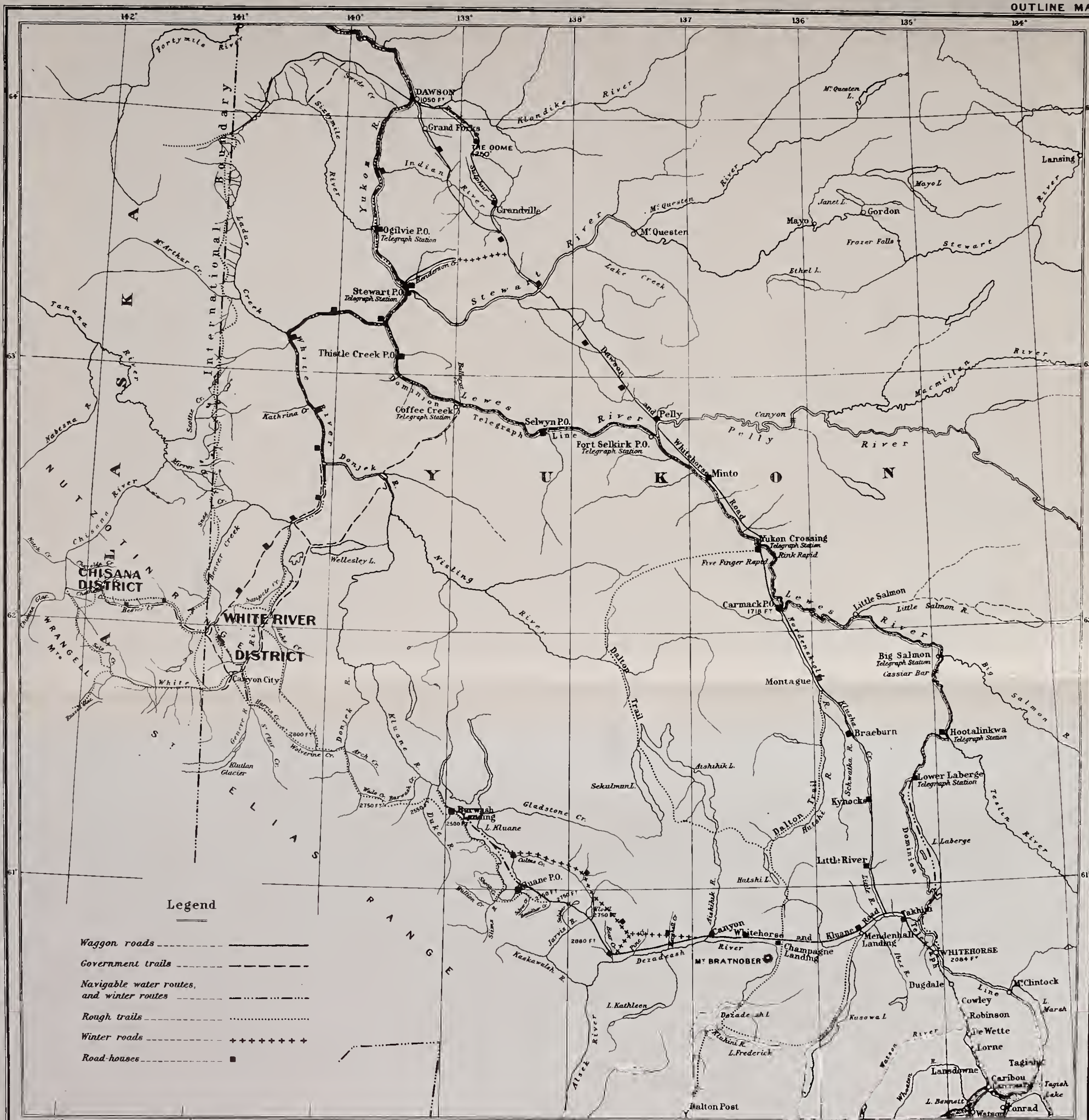
1.4.6 Historical Background

During the latter part of the last century a pack trail and wagon road was established from Burwash Landing on Kluane Lake northwestward to Canyon City in the White River mining district, near the Alaska border. It was used intermittently until the 1920s. Its southeast terminus at Burwash Landing was easily accessible via the government wagon road from Whitehorse to Kluane and then by boat or sled road across Kluane Lake (Cairnes 1913, 1915) (Figure 3).

Fiqure 3

Canada
Department of Mines
Hon L Coderre Minister R W Brock Deputy Minister
GEOLOGICAL SURVEY

OUTLINE MAP



C.O. Senécal, Geographer and Chief Draughtsman

MAP 113 A
(Issued 1916)

CANADIAN ROUTES TO WHITE RIVER DISTRICT, YUKON, AND TO CHISANA DISTRICT, ALASKA

Scale, 16 Miles to 1 Inch

To accompany Memoir by D D Cairnes

The first written documentation (Brooks 1899) referred to this route as the vestige of an old Indian trail which extended from the head of Lynn Canal (presently on the Alaska-British Columbia border) along the foothills of the St. Elias Mountains and into the White and Tanana River valleys (Figure 4). It was supposedly used extensively by the coast Indians during trading journeys into interior Yukon and Alaska.*

According to Father Huijbers of Burwash Landing (personal communication 1973) this route was also used by a "couple thousand" prospectors endeavoring to find an overland route into the Chisana District, Alaska, in the late 1800s. It is well known that many of the early prospectors followed old Indian trails when travelling overland in the Yukon. This wagon road and pack trail is thus an historical landmark.

1.4.7 Description of the Study Area

The intensive study area is centered along a 5 km stretch of this trail on the Burwash Uplands. The disturbed terrain varies from 5-13 m in width. Although the route has not been used for more than 50 years, it is still a remarkably

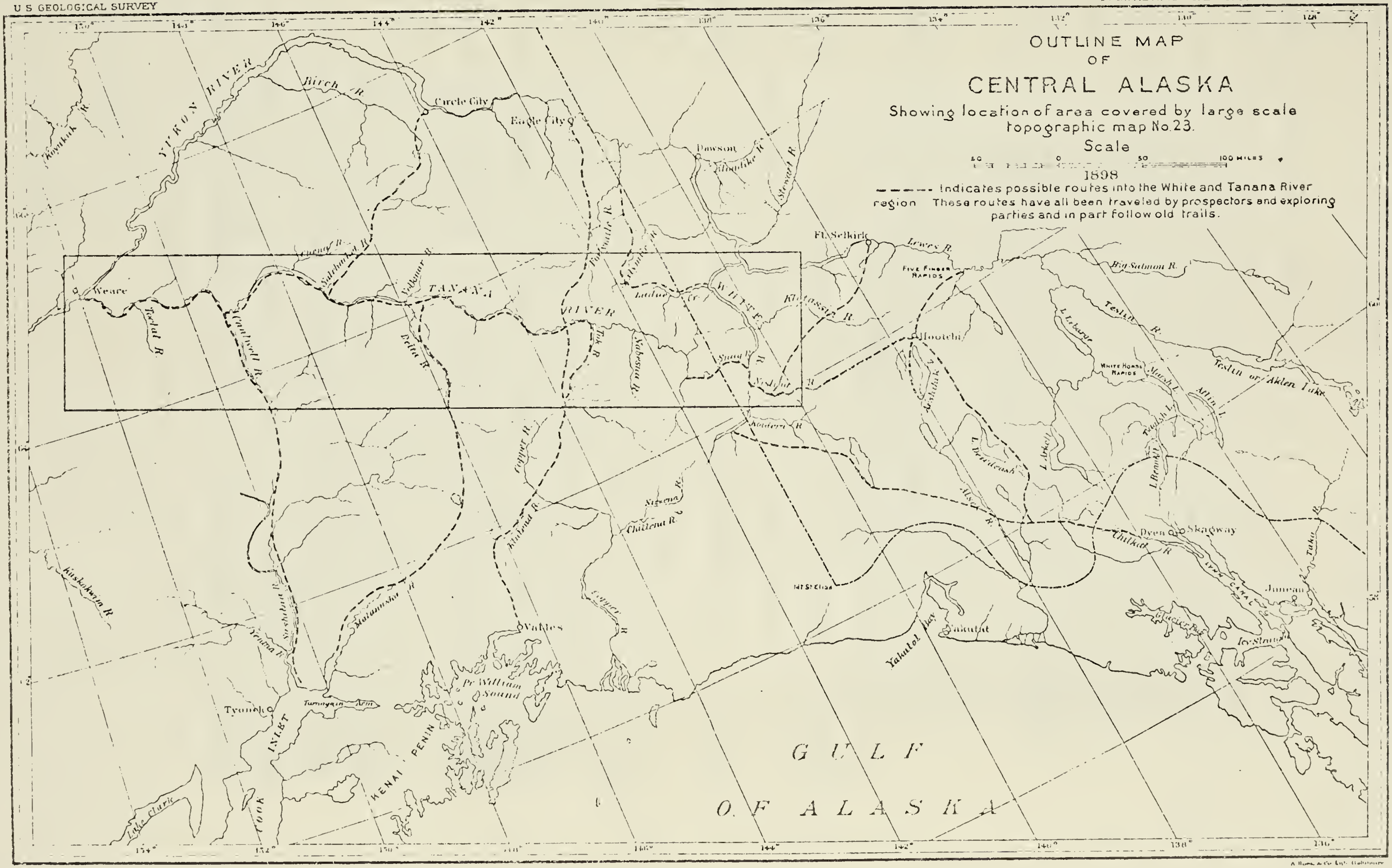
---

*The trading sojourns by the coast Indians, notably the Tlingit, into interior Yukon have been widely acclaimed. The Tlingit, astute middlemen, traded furs from the interior with the Russians on the coast for beads and knives. These, in turn were packed over the mountains to procure more furs from the interior Athapascans. These trading journeys bridged the 18th and 19th centuries, a continuity of almost 100 years (Fry 1971).

Figure 4

U S GEOLOGICAL SURVEY

TWENTIETH ANNUAL REPORT PART VII MAP NO.22



persistent landscape feature (Plate 2). On the Burwash Uplands, the road traverses a large area of sedge tussock tundra that is underlain by high ice-content permafrost. The road is particularly evident because the climax sedge (primarily *Carex bigelowii*) association has been largely replaced by a ground birch (*Betula glandulosa*) and willow (*Salix* spp.) plant community (Plate 3).

1.5 Study Design and Sampling Technique

In any ecological research a sampling strategy must be designed that is appropriate for the individual problem. The environmental disturbance under investigation may be considered a distinct ecosystem which encompasses a limited area and has sharply delineated physical and biological boundaries with the adjacent undisturbed terrain. The study was well suited for a systematic sampling technique: 15 equidistant paired plots were located along the center of the disturbed site and in adjacent undisturbed terrain 30 m from the edge of the disturbed location.

Quadrat size was defined as the smallest area which could effectively depict vegetation-permafrost-microrelief relationships. It was also desirable to maintain a uniform plot size to facilitate statistical comparisons. Quadrats measuring 2m x 2m were found to be the most feasible and manageable size.

Plate 2. Aerial view of the Burwash Trail across the Burwash Uplands. Although the trail has not been used for some 50 years it has persisted as a remarkable landscape feature.

Plate 3. Along the Burwash Trail the climax sedge tundra has been largely replaced by a birch-willow shrub community. Notice the accentuated microtopography and increased tussock growth which is due to thermomelioration and subsidence of the active layer following disturbance by man and subsequently by animals.

1.6 Length of Field Season

Field work was conducted during April 1973, June-September 1973, April and July 1974 and July 1975.

CHAPTER II

PERMAFROST DEGRADATION

2.1 Introduction

Permafrost is defined as the thermal condition of the ground when the temperature is continuously below 0°C for at least 1 year (Brown and Péwé 1973). Degradation of the permafrost occurs when the mean annual ground temperature rises above 0°C. Disruption of the ground thermal regime and subsequent thickening of the active layer may be induced by short term climatic oscillations, broad climatic changes, or surface disturbances. Seasonal year-to-year fluctuations in any one tundra site will rarely exceed 15% of the mean annual depth of thaw (Mackay 1970). Surface disturbance alters the ground-atmosphere heat exchange and causes a greater amplitude in the annual surface temperature (Gold and Lachenbruch 1973).

On the Burwash Uplands surface disturbance, initially through foot and wagon traffic and now similarly by animals, has caused degradation of the permafrost largely in the form of thermokarst subsidence. This is strikingly evident through accentuation of the microtopography along the path of the disturbance. It is hypothesized that compaction of the thick organic layer by man's activities caused thermomelioration and thermokarst subsidence, analagous to MacKay's (1970) observation on Garry Island where trampling by a tethered dog

caused the surrounding tundra surface to subside 18-23 cm in 2 years.

The purpose of this section is to compare the relationship and variance between microtopography and active layer development on disturbed and undisturbed terrain present in the study area. Two factors were chosen to analyze the type and degree of permafrost degradation: microtopography and depth of thaw.

2.2 Microtopography and Depth of Thaw

2.2.1 Introduction

The relationship, on a macroscale, between the configuration of the surface topography and development of the active layer has been well substantiated in the literature (Brown 1967, 1970, 1971; French 1970; Price 1971; and others). On a microscale there is increasing evidence that even small variations in relief can influence the distribution of permafrost and depth of the active layer (Gill 1971; Price 1971; Zoltai and Tarnocai 1971). Johnson (1969, p. 344) acknowledged the importance of the terrain factor in arctic ecosystem studies:

> What emerges from the description of arctic tundra is the impossibility of understanding tundra dynamics or even vegetation associations without a parallel examination of topographic microrelief, soils, and thaw depths that collectively constitute the substrate for plant life.

Recent studies have demonstrated that following surficial disturbance in areas containing high ice-content, fine-grained

soils, degradation of permafrost will be expressed on the surface through modification of the microtopography (Mackay 1970; Rempel 1970; Kerfoot 1972b; Heginbottom 1973.)

2.2.2 Methods

Microtopographic variations were accurately surveyed by a level line attached to stakes. Transects were run across each study plot on north-south compass lines (perpendicular to the line of disturbance.) The end points of each transect were marked with flagging tape; hence the same lines could be used to monitor active layer development throughout the summer thaw season. The highly irregular terrain, especially on disturbed sites, necessitated that line-to-ground measurements be taken at 10 cm intervals to obtain a precise survey of the surface microtopography. Sedge tussocks, a prominent microtopographic feature, were considered as part of the surface configuration; otherwise the top of the moss surface was regarded as the ground surface.

Depth-to-frost measurements were made 4 times during the summer thaw season from 30 June through 21 August (1973) along N-S transects in 15 paired study plots. Over 2500 measurements were gathered through this method. This information was supplemented by additional random point measurements in representative plant communities on disturbed and undisturbed sites. Two techniques were used to determine the rate and extent of frost retreat during the summer thaw season, a

metal probe and wooden dowels.

Probing with a metal rod is an efficient way to obtain large numbers of active layer depth measurements. Measurements were always taken from the moss or peat surface to the top of the frozen ground. In sedge tussock communities the height of the tussock above the moss or peat surface was subtracted from the probe reading. Field accuracy was within ± 1 cm.

The use of wooden dowels has been described by Gill (1971). Lengths of 0.9 cm wooden doweling were permanently inserted at the beginning of the field season in each study plot. As the thaw season progressed, the dowels were forced down to the frost table and the length of dowel protruding was subtracted from the known length.

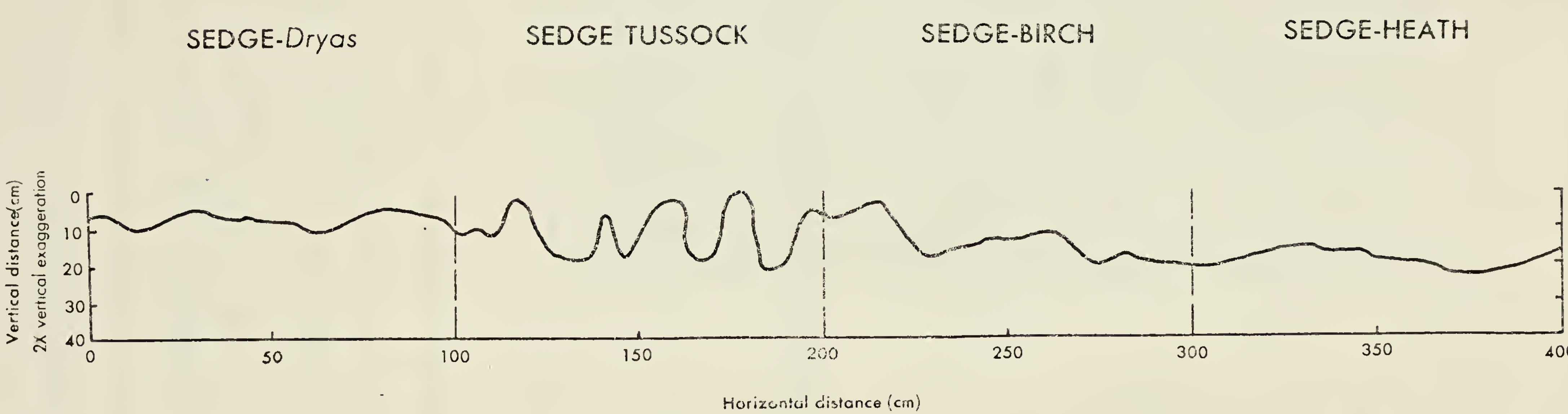
2.2.3 Results and Discussion

2.2.3.1 Influence of Microtopography on Active Layer Development

On the Burwash Uplands, there is a variety of micro-relief features which reflect the distribution of local plant communities. The interrelationship between frost action and vegetation is visibly manifested in the micro-topography. Surface variation on undisturbed sites in representative plant communities adjacent to the path of disturbance exhibits marked periodicity which reflects this soil-frost-vegetation interaction (Figure 5). Maximum microrelief occurs in sedge tussock communities while

Figure 5

MICROTOPOGRAPHY IN REPRESENTATIVE PLANT COMMUNITIES IN UNDISTURBED TERRAIN



sedge-heath communities are distinguished by minimal variation.

Along the trail the most noticeable microtopographic alteration has been the development of an extensive network of ruts which are highly conspicuous from the air (Plate 4). These thermokarst depressions (Section 2.1) range in depth from 20-50 cm. There is little evidence of fluvial erosion even where the trail crosses small swales and streams. Standing water is noted in many depressions after brief summer convection showers and longer rainy spells. After a late summer snowfall (13-16 August) snow persisted in the ruts long after it had melted elsewhere on the tundra surface (Plate 5).

Another prominent microtopographic consequence on disturbed sites has been the dramatic increase in density and size of sedge tussocks, primarily those of *Carex bigelowii* and *Eriophorum vaginatum*. The ecological significance of tussock development as a vegetative response to perturbation is expanded in Section 3.

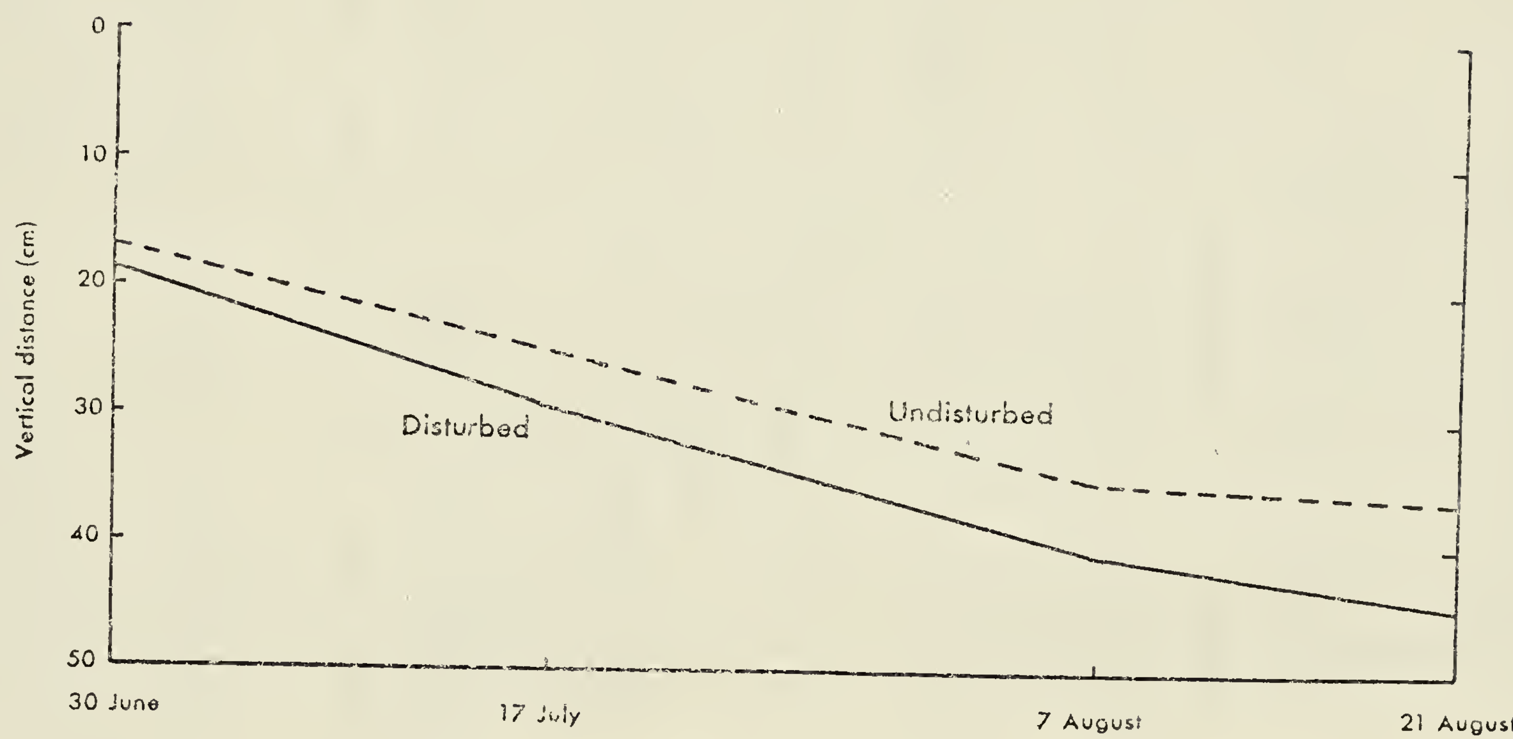
The microtopographic diversity caused by surface disturbance is reflected in the development of the active layer. Although the mean depth of thaw is 15-19% greater on disturbed sites (Figure 6), penetration of the 0° C isotherm in the disturbed area is much more irregular, largely resulting from topographic modification such as that caused by thermokarst subsidence. This is especially

Plate 4. Thermokarst processes are a direct result of man's activity in ice-rich permafrost. On the Burwash Uplands permafrost degradation is shown by the development of a conspicuous series of depressions and ruts. Currently, caribou help to maintain the degradation while foraging along the trail.

Plate 5. Snowdrifts are retained in thermokarst depressions along the Burwash Trail long after they have melted in the undisturbed sedge tundra (19 August 1973).

Figure 6

MEAN DEPTH OF THAW IN DISTURBED AND UNDISTURBED SITES DURING SUMMER 1973



true at the end of summer. Statistical data including the mean, maximum, minimum, standard error, standard deviation and coefficient of variation are summarized in Apprendix I.

The strong influence of aspect on disturbed sites is due to the greater microrelief. Transect 5a bisects a typical thermokarst depression formed along the disturbed terrain (Figure 7). On 21 August 1973, the mean depth of thaw at this site was 43.7 $\pm$ 3.4 cm. However, the thawed layer ranged in depth from a maximum of 72 cm on the south facing 'slope' to a minimum of 22 cm on the opposite slope for a difference in thaw penetration of more than 225% over a distance of 2 m.

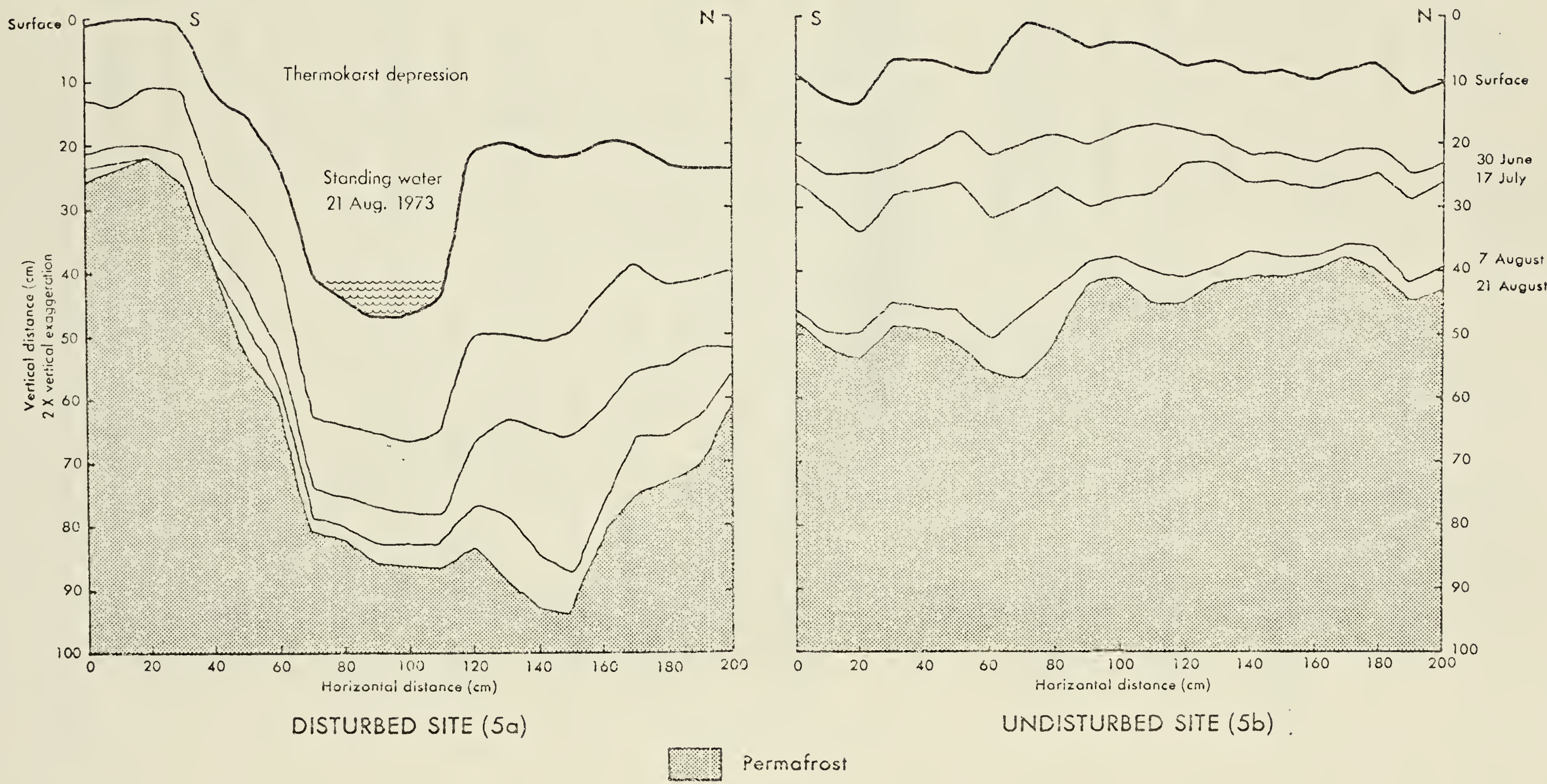
The comparative thaw profile in the adjacent site (Transect 5b) illustrates that undisturbed terrain has a more uniform frost table (Figure 7); this is further supported by the coefficient of variation statistic in which the disturbed site has a dispersion of almost twice that of the undisturbed site throughout most of the 1973 thaw season (Appendix I).

Although in these particular sites the mean thickness of the thawed layer showed no significant difference at the end of summer* ($t = -1.17$), the much greater amplitude of the thaw penetration in the disturbed site has ecological consequences which affect the presence and distribution of plant

*Table II shows however that between 30 June and 17 July, the disturbed sites possessed a significantly deeper thawed layer.

Figure 7

MICROTOPOGRAPHY AND DEPTH OF THAW
IN ADJACENT DISTURBED AND UNDISTURBED SITES DURING SUMMER 1973
(Transects 5a and b)



species and small mammal populations. This topic is discussed in Sections 3 and 4.

A further example of this type of degradation is depicted in Transect 3a (Figure 8) where the ground has differentially settled some 10-15 cm to cause a considerable depression in the frost table.

Thaw penetration in the undisturbed site proceeded at a slower rate and to significantly shallower depths (Table II). The more homogeneous terrain is also reflected in the less complex topography of the frost table.

2.2.3.2 Comparison of Thaw Depths on Disturbed and Undisturbed Sites: Paired Observations t-Test

One of the objectives of this study is to determine whether there are significant differences in the depth of thaw on disturbed and undisturbed terrain. Mean thaw depths in each of the paired (disturbed-undisturbed) sample plots were statistically tested by a paired observations t-test for each of the representative dates (Table II).

Interpretation of the t- values shows that there is a significant difference in thaw penetration on disturbed and undisturbed sites in 12 of 15 sample pairs with the exception of 7 August where it drops to 11 of 15 pairs. The direction of these differences is interesting. On 30 June, thawing was significantly deeper in 8 disturbed sites or more than half of the total sample paired plots versus 4 in the undisturbed sites. By the end of summer the ground had thawed

Figure 8

MICROTOPOGRAPHY AND DEPTH OF THAW
IN ADJACENT DISTURBED AND UNDISTURBED SITES DURING SUMMER 1973
(Transects 3a and b)

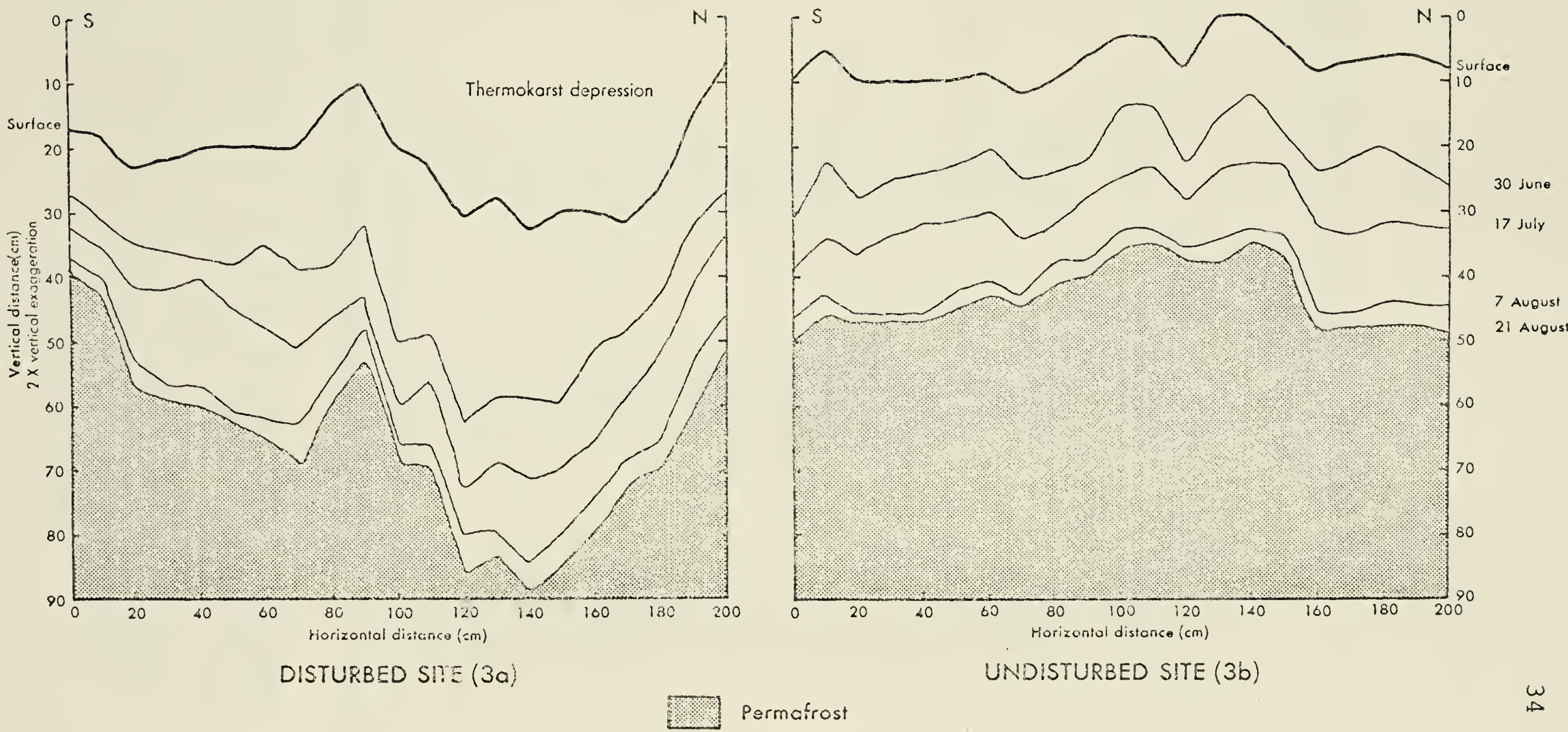


Table II

t-Test between mean active layer depths in

disturbed and undisturbed sites**

Paired Plots	June 30	July 17	August 7	August 21
1	-1.58*	-0.99*	-0.85*	-0.58*
2	-3.74	-3.33	-3.02	-2.02*
3	3.13	2.49	2.62	3.11
4	2.58	3.48	3.61	3.54
5	4.31	5.97	1.36*	1.17*
6	-6.52	-6.31	0.99*	2.28
7	-3.62	-1.38*	3.34	4.66
8	5.59	8.82	9.72	13.05
9	-5.14	-2.81	-3.79	-3.13
10	6.50	5.45	9.05	10.75
11	1.13*	-0.91*	2.92	6.88
12	3.12	4.18	3.28	4.22
13	0.78*	1.43*	3.71	4.09
14	2.80	4.98	1.88*	0.96*
15	7.68	13.52	19.80	15.29

*No significant difference between these disturbed and undisturbed means all others significant at $p < .05$ (N=21).

**The hypothesis being tested is that there are no significant differences in the active layer depths of disturbed and undisturbed sites (the null hypothesis). The critical value for the two-tailed test is where $t \leq -2.09$ and $t \geq 2.09$ (the five percent level of significance of the t distribution with 20 degrees of freedom). Sign indicates direction of significance (positive values for disturbed plots and negative values for undisturbed plots).

significantly deeper in 10 disturbed sites or two-thirds of the total sample pairs, as opposed to 1 undisturbed site. There was no statistical difference between the remaining 4 paired plots, an increase of 1 from 30 June.

The main conclusion that can be drawn from Table II is that although soil is thawed to greater depth on disturbed sites, the relationship is highly variable between sites. It can be explained in part by the great irregularity of disturbed terrain due to subsidence and tussock development. This, coupled with a greater use by animals of disturbed sites (e.g. trampling by caribou - Section 4.2.4) produces distinctive undulations in the frost table.

2.3 Summary

Disturbance of the organic layer above ice-rich permafrost on the Burwash Uplands has resulted in complex microrelief. This man-induced process has modified the tundra terrain by initiating physical, and subsequently biological, diversity along the Burwash Trail.

The distribution and diversity of tundra vegetation is closely related to surface microrelief, thus to understand secondary succession on disturbed terrain one must first understand the physical processes that create the substrate for plant regeneration.

CHAPTER III

VEGETATION and EDAPHIC MODIFICATION

3.1 Purpose

The intent of this chapter is to analyze the plant cover and soils of the study area including: 1) composition of the Burwash Uplands vegetation; 2) secondary plant succession on the Burwash Trail; 3) species diversity in climax and seral communities; 4) soil moisture - vegetation relationships; 5) soil organic content, pH, and available nutrients in undisturbed and disturbed sites.

3.2 Vegetation

3.2.1. Introduction

The organization of plant species at the community level is primarily controlled by the physical environment (Daubenmire 1968). Vegetation will consequently reflect the gradient of the environment (Whittaker 1953).*

In arctic and alpine regions environmental gradients tend to be steep resulting in intricate habitats and communities (Churchill and Hanson 1958). Frost action, an

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*In areas of gentle environmental gradients (e.g. a temperate mixed mesophytic forest) vegetation will likely form a continuum with overlapping dominants (cf. Gleason 1926; Curtis 1958). Vegetation which has developed along steep gradients will form discrete units with distinct boundaries.

important physical process in the tundra, contributes to microtopographical (thus environmental) diversity so that the mosaic of plant communities can usually be correlated with the type and intensity of frost action (Benninghoff 1952; Sigafoos 1952). Therefore in a steep gradient environment such as on the Burwash Uplands, plant communities will commonly have distinct boundaries with narrow ecotones.

On the Burwash Uplands environmental disturbance has created a new habitat for plant colonization. This man-modified landscape feature has obvious and well-defined boundaries which can be used to form the basis of vegetation analysis in the study area.

3.2.2. Floristic Analysis

3.2.2.1. Methods

The unit approach to vegetation analysis was adopted and followed (in a modified form) the phytosociologic methods of Braun-Blanquet (1932). Modifications of the Braun-Blanquet system of vegetation analysis have been successfully used in a number of northern ecological studies (Hanson 1953; Churchill 1955; Ritchie 1959; Jeffrey 1964; LaRoi 1967; Gill 1971). The Braun-Blanquet method was considered applicable to the present study because plant communities form distinct units with identifiable floristic differences which are separated by sharply defined boundaries.

An initial survey identified the major communities along the trail. The Braun-Blanquet indices of cover-abundance, sociability, and stratification were analyzed in systematically located paired (undisturbed-disturbed) sample plots (see Section 1.5).

After completion of the floristic analysis specimens of vascular plants, bryophytes, lichens, and fungi were collected in each sample plot. Plants were pressed in the field and returned to Edmonton. Identifications or verification of difficult vascular species and mosses were made by W. J. Cody, Biosystematics Research Institute, Ottawa, Ontario. The lichens were identified by Dr. I. Brodo, National Museum of Canada and the fungi by Dr. Malloch, Biosystematics Research Institute, Ottawa, Ontario. A complete set of voucher specimens is in the Department of Geography Herbarium, The University of Alberta. A partial collection is deposited in the Herbaria of the Biosystematics Research Institute, Ottawa, Canada. Nomenclature follows Hultén (1968) for vascular species, Crum *et al.* (1973) for bryophytes, and Hale and Culberson (1970) for lichens. A systematic tabulation of these species is contained in Appendix II.

Cover-abundance was described according to a 9-point scale as used by Krajina (1961) and modified by Gill (1971).

TABLE III

Cover-Abundance Index

1. Occurring seldom, cover negligible
2. Rare, covering up to 5% of the plot
3. Common, covering 6-10% of the plot
4. Occurring often, covering 11-20% of the plot
5. Occurring very often, covering 21-35% of the plot
6. Abundant, covering 36-50% of the plot
7. Abundant, covering 51-75% of the plot
8. Very abundant, covering 76-95% of the plot
9. Very abundant, covering 96 100% of the plot

A second value denotes the sociability of each species.

TABLE IV

Sociability Index

1. Growing singly
2. Grouped or tuffed
3. Growing in small patches or cushions
4. Growing in small colonies, extensive patches or forming carpets
5. Forming pure populations

Component species were assigned to the appropriate stratification class.

TABLE V

Stratification Index

Shrub Layer B (below 2m)
Herb Layer C*
Moss Layer D**

*Salix reticulata and members of the Empetraceae, Ericaceae, and Rosaceae present in the study area are included in the Herb Layer due to their decumbent growth form.

**Lichens are included in the moss stratum.

3.2.2.2 Results and Discussion

3.2.2.2.1 Vegetation Tables

The purpose of a schematic arrangement of the component species into vegetation tables is to illustrate the essential structural and floristic characteristics of an association in model form (cf. Moore 1962).

Physiognomic and floristic data for representative plant communities are presented in Tables VI and VII. For every sample plot, each species is first placed in the proper stratum and then assigned a combined cover-abundance value followed by its sociability (spacing or aggregation of species).

TABLE VI

Cover-Abundance and sociability of vegetation on undisturbed sites

Stratum & Species	Plot No.														
	Sedge Tussock					Sedge Birch	Sedge-Heath								Sedge-Dryas
	2	3	4	6	9	10	5	7	8	11	12	13	14	15	1
Shrub Layer (below 2m)															
Betula glandulosa	1-1	3-2	2-2	2-2		2-1	4-2	1-1			2-3	2-2	3-2	1-1	
Salix glauca	2-1						3-2		3-2	1-1					
Salix pulchra		1-2													
Herb Layer															
Carex bigelowii	4-2	5-2	6-2	6-2	7-2	5-2	4-2	7-2	6-2	6-2	6-2	6-2	6-2	6-2	5-2
Salix reticulata	3-3	4-3	4-3	3-3	3-3	4-3	3-4	3-3	2-3	2-3		2-3	2-3	2-3	4-3
Dryas integrifolia	3-3	2-3	3-3	2-3	2-3	3-3	2-3	3-3	2-3	3-3	2-3	2-3	2-3	1-2	5-4
Eriophorum vaginatum	6-2	5-2	2-2	5-2	3-2	4-2		1-2	2-2		1-2		1-2		
Arctostaphulos rubra	2-3				1-3	2-3		4-3	4-3	5-4	1-3			3-3	1-3
Polygonum bistorta	1-1		1-1			2-1									
Carex membranacea			2-2												
Carex aquatilis			2-2												
Carex atrofusca			2-1												
Eriophorum angustifolium	2-1			1-1		1-1									
Rubus chamaemorus		1-1		1-1											
Potentilla fruticosa				1-1	1-1										
Tofielda pusilla				1-1											
Festuca altaica	1-1														
Pedicularis sudetica			1-1		1-1										
Saxifraga hirculus					1-1										
Cortinarius sp.		1-1	1-1	1-1		1-1	1-1		1-1	1-1					
Pedicularis oederi	1-1			1-1		1-1				1-1					
Pyrola grandiflora	1-1		1-1			1-1									
Pedicularis arctica	1-1		1-1			1-1						1-1			
Rhododendron lapponicum	1-1			1-1		1-1		1-1	1-1			1-1	1-1		1-1
Ledum palustre	1-1											1-1			
Vaccinium uliginosum				2-2				2-2	3-2		4-2			1-1	
Polygonum viviparum					2-1			2-1	1-1	2-1	2-1				
Eriophorum brachyantherum							3-2					3-2	4-2	3-2	1-1
Vaccinium vitis-idaea										2-2		2-1	2-1	2-1	1-1
Lupinus arcticus								1-1	1-1						1-2
Empetrum nigrum								2-2				3-2		2-2	
Pedicularis lanata								1-1	1-1	1-1	1-1	1-1		2-1	1-1
Anemone narcissifolia														3-2	
Cassiope tetragona														1-1	
Arctagrostis arundinacea												1-1			
Dryas octopetala														1-1	2-1
Papaver lapponicum															2-3
Silene acaulis															1-1
Moss & Lichen Layer															
Rhytidium rugosum	6-3	2-3	6-3	5-3	6-3	7-3	6-3	7-3	7-3	8-3	8-3				1-3
Thuidium abietinum	2-3	4-3	4-3	4-3	6-3	3-3	4-3	4-3	3-3	3-3	1-3				
Polytrichum strictum	2-3		2-3	3-3											
Aulacomnium palustre	1-3	2-3			1-3		2-3					8-3	6-3	7-3	5-3
Cetraria cucullata	2-3				1-3		2-3			1-3	1-3	2-3	4-3	5-3	1-3
Thamnolia vermicularis											1-3				
Physconia muscigena	1-3		1-3	1-3			1-3					2-3	1-3	2-3	
Dicranum sp.	1-3					1-3						2-3	2-3	1-3	
Cladonia pyxidata												1-3			
Cladonia fimbriata															1-3
Cladonia sp.						1-3									1-3
Stereocaulon alpinum															1-3

TABLE VII

Cover-abundance and sociability of vegetation on disturbed sites

Stratum & Species	BIRCH-WILLOW ASSOCIATION (Plot No.)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shrub Layer (below 2 m)															
Betula glandulosa	5-2	2-2	5-2	4-2	2-1	5-2	3-2	5-2	2-1	4-2	5-2	5-2	5-2	5-2	5-2
Salix glauca	2-2	6-2	2-2	5-2	7-2	5-2	4-2	4-2	5-2		3-2	4-2			5-2
Salix pulchra					3-2		6-2	3-2	4-2	6-2	6-2	3-2	5-2	4-2	4-2
Salix arbusculoides					2-2			2-1			1-2			2-1	2-1
Salix barrattiana	2-2														
Herb Layer															
Carex bigelowii	5-2	4-2	5-2	4-2	6-2	5-2	6-2	3-2	3-2	6-2	6-2	4-2	5-2	6-2	2-2
Eriophorum vaginatum		6-2	2-2		2-2	5-2	4-2	5-2	2-2	4-2	3-2	1-2	4-2	5-2	
Salix reticulata	4-4	2-3	3-3	2-2	2-2	1-2	2-3	2-3	1-3	2-3	1-3	1-3	1-3	1-3	1-2
Vaccinium uliginosum	1-1			2-2				3-2		1-2	2-2	5-2	3-2	1-2	4-2
Arctagrostis arundinacea	2-2		1-2	2-2	2-2		1-2	2-2		2-2		2-2	2-2		3-2
Polygonum bistorta	2-1	1-1		1-1	1-1	1-1	1-1	1-1	1-1	2-1	1-1	1-1	1-1	1-1	
Pyrola grandflora		1-1	1-1	1-1	2-1			1-1	1-1	1-1	1-1	1-1			
Vaccinium vitis-idaea								2-2	2-2	1-2		1-2			4-2
Empetrum nigrum								1-2	2-2			2-2			4-2
Festuca altaica						2-2		2-2	1-2		2-2				
Carex aquatilis				3-2		4-2									
Carex membranacea					2-2	2-2							3-2		
Petasites frigidus			3-2	2-2	1-1		1-1			1-1					
Potentilla fruticosa	1-1	1-1	1-1			1-1	1-1		1-1						
Valeriana capitata				1-1	1-1		1-1	1-1			1-1		1-1		
Oxytropis maydelliana	1-1						1-1	1-1		1-1	1-1				
Arctostaphylos rubra								1-2		2-3					1-2
Eriophorum brachyantherum		2-2		2-2											
Anemone narcissiflora			1-1	1-1	1-1					1-1					
Ledum palustre												2-1			2-1
Saxifraga hieracifolia					1-1			1-1		1-1	1-1				
Saxifraga hirculus				1-1				1-1		1-1				1-1	
Eriophorum angustifolium				1-1		2-2									
Astragalus umbellatus					1-1		1-1	1-1		1-1	1-1				
Polemonium acutiflorum					1-1			1-1			1-1	1-1			
Lupinus arcticus	1-1				1-1										1-1
Pedicularis arcticus															1 1
Rhododendron lapponicum								1-1		1-1			1-1		
Anemone parviflora									1-1	1-1					
Cardamine sp.			1-1		1-1										
Dryas integrifolia	1-1					1-1									
Gentiana prostrata					1-1	1-1									
Gentiana propinqua					1-1	1-1									
Mertensia paniculata								1-1					1-1		
Parrya nudicaulis										1-1	1-1				1-1
Pedicularis oederi	1-1														1-1
Pedicularis sudetica			1-1												1-1
Polygonum viviparum			1-1												1-1
Senecio lugens								1-1					1-1		
Solidago multiradiata											1-1		1-1		
Stellaria monatha					1-1	1-1									
Aconitum delphiniflorum									1-1						
Dryas octopetala										1-3					
Eutrema edwardsii						1-1									
Gentiana algida													1-1		
Papaver lapponicum	1-1														
Parnassia palustris var. *neogaea*											1-1				
Pedicularis capitata											1-1				
Pedicularis labradorica			1-1												
Potentilla diversifolia										1-1					
Saussurea angustifolia									1-1						
Senecio atropurpureus											1-1	1-1			
Senecio resedifolius								1-1							
Moss & Lichen Layer															
Aulacomnium palustre	6-3	3-3	4-3	6-3	5-3	3-3	6-3	7-3	7-3	5-3	5-3	7-3	6-3	4-3	5-3
Thuidium abietinium		1-3		-	3-3		1-3	2-3	2-3	1-3	2-3	2-3	2-3	2-3	2-3
Dicranum elongatum		1-3	1-3	2-3	1-3				1-3		2-3				
Leptobryum pyriforme	1-3		1-3		2-3	1-2		2-3	1-2		1-3				2-3
Polytrichum strictum				1-3			2-3	1-3			1-3				
Physconia muscingena		1-3		1-3	1-3	1-3	1-3		1-3	1-3		1-3	1-3		2-3
Cetraria cucullata									1-3						1-3
Stereocaulon alpinum															1-3

3.2.2.2.2 Vegetation of Undisturbed Sites*

Sedge Association

A climax** sedge association occupies most of the alpine tundra along the Burwash Trail. Sedges cover 50-60% of the vegetated surface. The ubiquitous tussock-forming sedge *Carex bigelowii* comprising 30% of the plant cover, is the single most important species in the climax tundra (Table VI). The sedge association is classified into 4 subassociations on the basis of physiognomy and occurrence of certain species.***

1) Sedge-tussock subassociation
2) Sedge-heath subassociation
3) Sedge-birch subassociation
4) Sedge-*Dryas* subassociation

1. Sedge-tussock subassociation

This community occurs extensively on the poorly drained flat lying uplands (Plate 6). It is similar to the

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*Vegetation sampling was restricted to communities present along the trail.

**The term 'climax' implies the relatively steady state condition of a natural community which is in dynamic equilibrium with its environment (Whittaker 1970). The concept of climax in arctic and alpine ecosystems remains unclear, however, due to the apparent instability of the environment. Application of the climax theory must consider present environmental and vegetation changes occurring in steady state communities (Churchill and Hanson 1958).

***Further differentiation of plant communities could have been extended. To do so would have been beyond the purpose of the study.

tussock communities described in northwest Alaska by Hanson (1953) and the Seward Peninsula by Hopkins and Sigafoos (1951). *Carex bigelowii* and *Eriophorum vaginatum* are the dominant tussock-forming sedges.

Dwarf shrubs such as *Betula glandulosa* and *Salix glauca* are widely scattered throughout tussock communities but constitute little cover.

Salix reticulata and *Dryas integrifolia* are important decumbent shrubs growing on or around the tussocks. Moist depressions around tussocks support a variety of minor species such as *Potentilla fruticosa, Rhododendron lapponicum, Pyrola grandiflora* and a number of *Pedicularis* species. The presence of *Rubus chamaemorus, Tofielda pusilla, Polygonum bistorta,* and *Saxifraga hirculus* attest to hygric* conditions in the tussock community (Hultén 1968).

Rytidium rugosum and *Thuidium abietinum* are the dominant bryophytes in the well-developed moss stratum. *Cetraria cucullata* and *Physconia muscigena* are frequent species with low cover in the impoverished lichen flora.

2. Sedge-heath subassociation

Near the trail this community occurs on the slightly drier, gentle north facing slopes (Plate 7). Microtopography is subdued though frost boils are common in some locations.

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*Hygric refers to a site that provides constantly wet or waterlogged soil conditions or the quality of a plant that is adopted to such conditions.

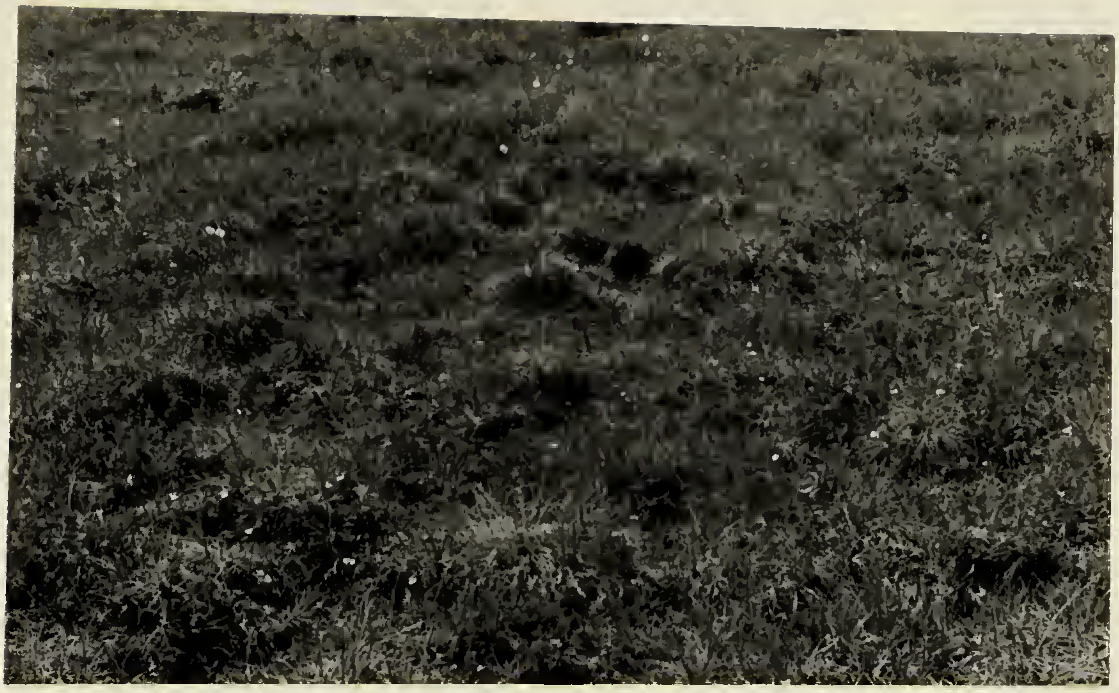

Plate 6. The tussock-forming sedges *Carex bigelowii* and *Eriophorum vaginatum* dominate the sedge tussock community. This community covers most of the flat-lying upland surface.

Plate 7. Close-up view of the sedge-heath community adjacent to the Burwash Trail. *Carex bigelowii*, the dominant sedge, loses its tussock growth form in this community. Numerous ericaceous species such as *Arctostaphylos rubra, Vaccinium uliginosum* and *Empetrum nigrum* (shown here) are common on gentle north facing slopes along the trail.

Carex bigelowii is still the most prominent vascular species but the tussock growth form is less prevalent. *Eriophorum vaginatum* is greatly reduced or absent in sedge-heath communities.

Betula glandulosa and *Salix glauca* are frequent shrubs with low cover-abundance (~5%).

The herb-low shrub layer contains numerous ericaceous species inclduing (in order of descending cover-abundance) *Vaccinium uliginosum, Arctostaphylos rubra, Vaccinium vitis-idaea, Rhododendron lapponicum, Cassiope tetragona,* and *Dryas integrifolia* as important secondary species. *Polygonum viviparum,* a common circumpolar tundra species, has a high frequency but constitutes < 5% of the plant cover.

The ground surface has an essentailly continuous bryophyte cover (75-100%). *Rhytidium rugosum* and *Thuidium abietinum* are dominant species with high cover-abundance values. Lichens are more frequent than in tussock communities but constitute < 5% of the cryptogram stratum. *Cetraria cucullata* and *Thamnolia vermicularis* are the most common species.

3. <u>Sedge-Birch Subassociation</u>

The sedge-birch community is infrequent near the Burwash Uplands trail. Elsewhere it is restricted to elevated and better drained areas along ridges or stream valleys.

The shrub stratum has a moderately high cover (25%) of *Betula glandulosa* and *Salix glauca*.

Sedges, mainly *Carex bigelowii*, dominate the herb layer.

The cryptogam stratum (mostly bryophytes) is well developed with a cover of 75%. *Rytidium rugosum* and *Thuidium abietinum* are the most prominent mosses. *Cetraria cucullata* and *Physconia muscigena* are the only species of the depauperate lichen flora.

4. Sedge-Dryas Subassociation

Near the trail this rare community is restricted to slightly raised sites such as around frost boils. In alpine tundra other stands were noted on drier south-and east-facing slopes mostly at higher elevations. Exposed mineral soil, sparse moss cover and upheaved rocks suggest frequent disturbance by frost action.

The herb stratum is dominated by *Carex bigelowii*, *Dryas integrifolia* and *Salix reticulata*. The presence of *Arctagrostis arundinacea* is also an indicator of the disturbed substrate. Several other species of the community contribute little cover but were not observed elsewhere in the undisturbed vegetation along the trail. They are: *Dryas octopetala*, *Papaver lapponicum* and *Silene acaulis*.

Rhytidium rugosum is the dominant bryophyte in the crypotogam stratum. Lichen cover is sparse and includes *Cladonia fimbriata*, *C. pyxidata* and *Stereocaulon alpinum*.

3.2.2.2.3 Vegetation of Disturbed Sites

Birch-Willow Association

This low shrub community has developed along the Burwash Trail in response to favorable allogenic* changes following disturbance.

The vegetation (Table VII) is distinguished by a much higher cover-abundance of shrub species, especially *Betula glandulosa, Salix glauca,* and *Salix pulchra* (Plate 8). Johnson *et al.* (1966) reported that these two willow species often occupy disturbed sites around ground squirrel burrows on the arctic slope of Alaska. *Salix arbusculoides* was not detected in the climax vegetation (Table VI), although it does grow occasionally along protected streambanks on the uplands.

Carex bigelowii and *Salix reticulata,* dominant plants of the undisturbed vegetation, retain their importance in the successional community. *Eriophorum vaginatum,* common in undisturbed tussock communities but rare in heaths, has proliferated greatly all along the trail. Palmer and Rouse (1945) observed, in Alaska, that *Eriophorum* was the chief invader in hygric sites following trampling by reindeer. On the Burwash Trail, *Carex bigelowii* and *Eriophorum vaginatum* have responded to perturbation by increased reproductive and

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*Allogenic refers to succession influenced by physical elements of the environment (Dansereau 1957).

Plate 8. Dense shrub stand along the trail dominated by *Betula glandulosa*, *Salix pulchra*, and *S. glauca*. Metal probe extends 1.5 m above ground surface. Note elongated thermokarst depression in foreground.

vegetative growth (Plates 9, 10). The impressive ability of these species to colonize disturbed areas is well documented (Wein and Bliss 1973, 1974; Wein 1973). Subsequent to disturbance these species are known to regenerate from roots and rhizomes and to undergo stimulated growth (Hernadez 1973).

Statistically significant differences in the size of *Carex bigelowii* and *Eriophorum vaginatum* tussocks was determined through random measurements in undisturbed and disturbed sites (Table VIII).

TABLE VIII

Mean ($\pm$S.E.) size of *Carex bigelowii* and *Eriophorum vaginatum* tussocks on undisturbed and disturbed sites (N=25).

Dimension (cm)	Undisturbed	Disturbed
Mean Diameter	20.7 $\pm$ 2.2	30.9 $\pm$ 3.3*
Mean Height	14.3 $\pm$ 2.0	26.4 $\pm$ 2.8*

*P > .01 when compared to undisturbed

The high frequency of *Arctagrostis arundinacea** and *Festuca altaica* testifies to the disturbed conditions of the soil. The former is one of the most successful invaders of seismic lines and other disturbed areas in the low arctic (Bliss and Wein 1972; Hernandez 1973).

**Arctagrostis latifolia* of some authors.

Plate 9. Dense and tall growth of *Carex bigelowii* tussocks on Burwash Trail.

Plate 10. Well developed *Eriophorum vaginatum* tussock on trail. Low shrub around tussocks is *Salix glauca*.

Species richness along the trail is fostered by the wide range of habitats provided by the diverse microtopography. Wet thermokarst depressions are populated by hygrophytes such as *Petasites frigidus, Saxifraga hirculus, Cardimine* sp., *Gentiana prostrata,* G. *propinqua, Stellaria montha,* and *Eutrema edwardsii.* With the exception of *Saxifraga hirculus* these species are found only in the successional stands on disturbed sites. More elevated mesic sites are colonized by *Empetrum nigrum* and ericaceous species, notably *Vaccinium uliginosum,* V. *vitis-idaea.* The more dense shrub canopy has probably contributed to the increased abundance of commonly shade-tolerant species such as *Pyrola grandiflora.*

Many infrequent herbaceous species in the birch-willow association are not found in the adjacent undisturbed tundra but are typical to streambanks which cross the trail in several places (Plate 11). It is probable that as new sites were exposed, seeds from these streambank communities, transported by winds, animals and humans, effectively colonized favorable locations along the trail. In order of importance they are: *Petasites frigidus, Valeriana capitata, Polemonium acutiflorum, Mertensia paniculata, Parrya nudicaulis, Senecio lugens, Solidago multiradiata, Aconitum delphiniflorum, Parnassia palustris, Saussurea angustifolia, Senecio atropurpureus,* and S. *resedifolius.*

Plate 11. Minor disturbances along the Burwash Trail have had an ameliorating effect on some factors of the physical environment which has enabled species to invade from surrounding streambanks that cross the trail.

The cryptogam stratum is not as well developed as in the undisturbed communities (Tables VI and VII). *Aulacomnium palustre*, the dominant bryophyte, achieves its greatest coverage under dense *Salix* stands. The less frequent *Dicranum elongatum* occurs under willows and in depressions. It is interesting that *Leptobryum pyriforme*, a frequent moss on the trail, is not found in the adjacent climax sedge tundra. In the Mackenzie Delta this bryophyte inhabits *Equisetum* communities that are subject to frequent disturbances through annual flooding and sedimentation (Gill 1973). The meager lichen flora is dominated by *Physconia muscigena*. This is not surprising in that lichens are not abundant on the Burwash Uplands and are notably degraded by disturbance; furthermore, they have a slow regeneration rate (cf. Palmer and Rouse 1945; Scotter 1964.)

3.2.3 Comparison of Vegetation on Undisturbed and Disturbed Sites

3.2.3.1 Average Total Coverage

The most striking difference in plant cover between undisturbed and disturbed areas is the increased shrub cover on the trail (Table VII; Plates 3, 8.) The herb stratum has less cover-abundance on the trail than on undisturbed sites. This may be due to (1) reduction of the solar radiation by a dense shrub canopy which reduces the number of shade intolerant species; (2) continuous disturbance by caribou

and small mammals along the trail which creates a difficult environment for the colonization of some species.

Cryptogams, usually slow colonizers, are significantly reduced in disturbed areas (Table IX).

TABLE IX

Mean (±S.E.) percentage cover by stratum on undisturbed and disturbed sites (N=15).

Stratum	Undisturbed	Disturbed
Shrub	5.1 ± 1.6	56.0 ± 3.5*
Herb	72.5 ± 2.4	62.3 ± 3.0**
Moss/Lichen	73.7 ± 5.3	42.7 ± 5.8*

*P < .01 when compared to undisturbed
**P < .02 when compared to undisturbed

3.2.3.2 Species Diversity

One of the most commonly cited indices of diversity is species richness or the number of species present. Examination of richness by stratum indicates a greater diversity in the shrub and herb layers of the successional community along the trail.

Moss-lichen diversity is unchanged (Table X).

TABLE X

Species richness by stratum on undisturbed and disturbed sites (N=15).

Stratum	Undisturbed	Disturbed
Shrub	1.3	2.9*
Herb	9.9	13.3**
Moss/Lichen	3.8	3.8

*P < .01 when compared to undisturbed
**P < .02 when compared to undisturbed

3.2.4 Summary

Following a temporary disturbance, plant succession normally returns a disturbed community to its original vegetation. The extent of this step-by-step replacement depends largely on the type and degree of disruption and local environmental conditions (Daubenmire 1968; Horn 1974).

Most theories of plant succession have been formulated in the temperate regions of the world (cf. Whittaker 1957, 1965; Odum 1971), thus the successional sequence following a disturbance by trail-making activities in a temperate grassland or woodland could be reasonably predicted (cf. Shantz 1917).

In arctic and alpine tundra, permafrost is an environmental factor which has a significant influence on plant growth and community pattern. It follows that degradation of

the permafrost may modify the substrate sufficiently to initiate a different successional sequence than would be expected in a non-permafrost environment.

Unfortunately there have been few longterm successional studies in permafrost environments. Most of the documented vegetation changes associated with disturbances in the North can be termed 'retrogressive.'* In the Mackenzie Delta for example, clearcutting of the climax white spruce (*Picea glauca*) association on elevated exposed sites resulted in the establishment of tundra vegetation (Gill 1973). Similarly, Kryuchkov (1968) noted in Siberia that fire disturbance in northern forests caused a 'pyrogenic' tundra to develop. Hernandez (1973) has shown that secondary succession following tundra disturbance in the Tuktoyaktuk region is proceeding but after six years the plant cover is only 30-50% on exposed mineral soil.

Minor disturbances along the Burwash Trail have had an ameliorating effect on some factors of the physical environment. As new openings were made available, replacement of the climax sedge association by a predominant shrub community has allowed species to invade that are not found in the surrounding climax vegetation.

3.3 Edaphic Modification

3.3.1 Introduction

In the North, vegetation-soil relationships are closely

*Retrogressive signifies the directional change from a more complex to a less complex community (Whittaker 1970).

linked to the presence of permafrost and intensive frost action (Tyrtikov 1959; Radforth 1965; Viereck 1970; Raup 1971; Brown and Williams 1972.) Disturbance of the active layer is usually accompanied by vegetation changes which alter the physical and chemical properties of the soil. This section investigates the degree to which such physical and biological changes have modified various aspects of soil development in the study area.

3.3.2 Methods

3.3.2.1 Soil Moisture

Soil water content was determined by collecting field samples in metal containers that were sealed against evaporation loss. The samples were later processed in the laboratory by standard evaporation methods (Black 1965.)

3.3.2.2 Organic Content

An estimate of organic content was made by the loss-on-ignition method (Ball 1964.) Samples were weighed and dried overnight in a forced draft oven at 110°C, reweighed and then ignited in a muffle-furnace at 375°C for 16 hours. The loss-on-ignition is expressed as the percentage of weight loss after drying.

3.3.2.2 Soil Reaction

Soil reaction was determined in the laboratory with a calibrated glass electrode pH meter. A 1:1 ratio of soil to water was used following the method described in Black (1965).

3.3.2.3 Soil Nutrients

Samples from undisturbed and disturbed sites were analyzed for available nitrogen, calcium, magnesium, sodium, and potassium by the Alberta Institute of Pedology.

3.3.3 Results and Discussion

3.3.3.1 Soil Moisture and Organic Content

Measurements of soil water and organic matter are important aspects of thermokarst investigation. Furthermore, permafrost studies have also emphasized the importance of plant cover and organic material to the ground thermal regime (Tyrtikov 1959; Brown 1965). Tyrtikov (1959, p.3) writes:

> . . . the most important changes which influence the moisture regime between the soil and the atmosphere result from the accumulation of organic material.

In the study area, differences in soil moisture are essentially dependent on two interrelated factors: microtopography and plant cover with its accompanying organic buildup.

A transect across a typical thermokarst depression in the birch-willow community (Figure 9) demonstrates the relationship between microtopography, depth of thaw, and soil moisture. The moist depressions typically have a thinner active layer than the more elevated exposed (and drier) hummocks.

In the adjacent undisturbed site (Figure 10) soil moisture values are higher and more uniform due to the thick organic mat and low microrelief. It follows that thaw

Figure 9

SOIL MOISTURE AND DEPTH OF THAW ON DISTURBED SITE Transect 15 a
(soil moisture measurements taken on 21 Aug. 1973)

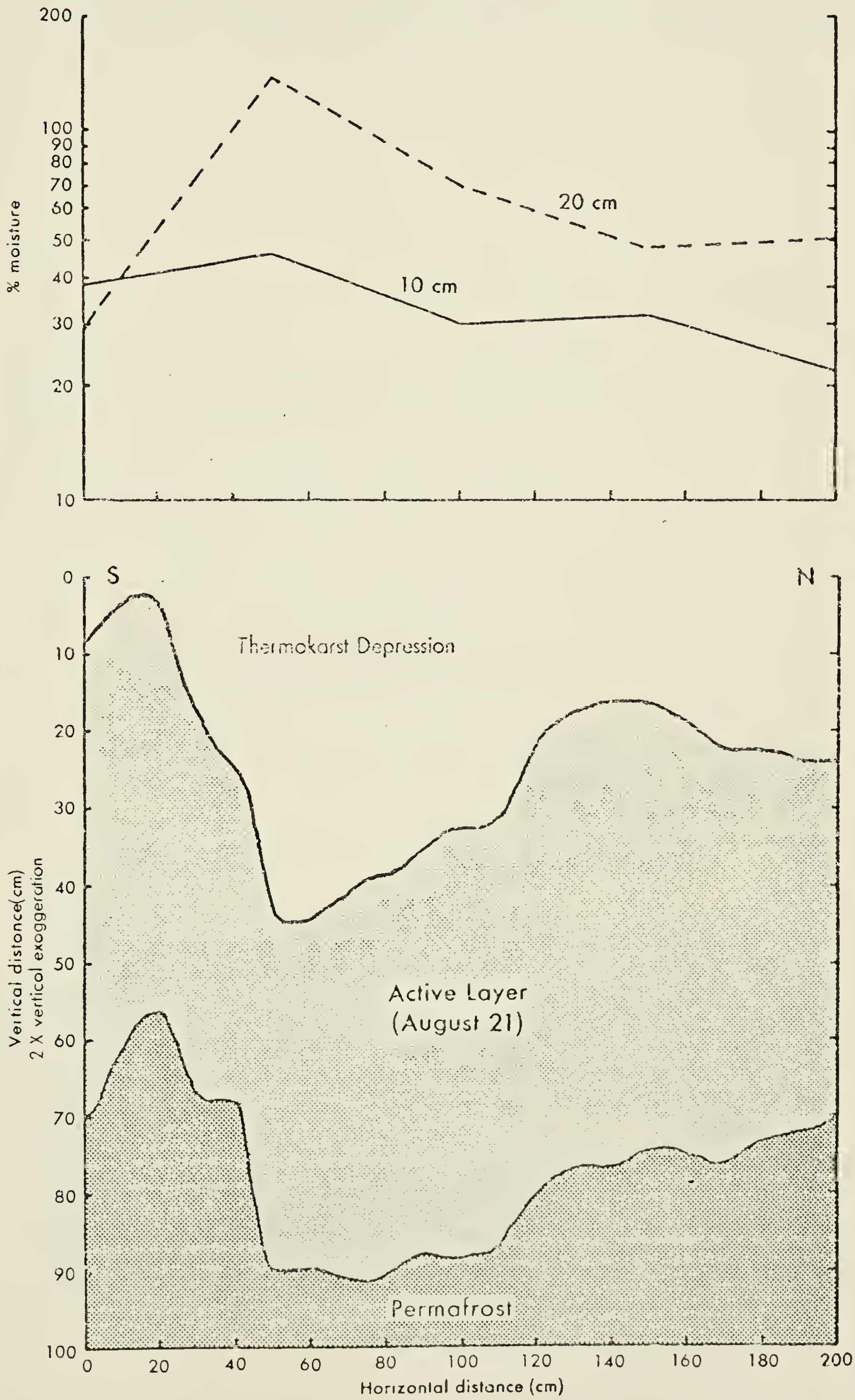
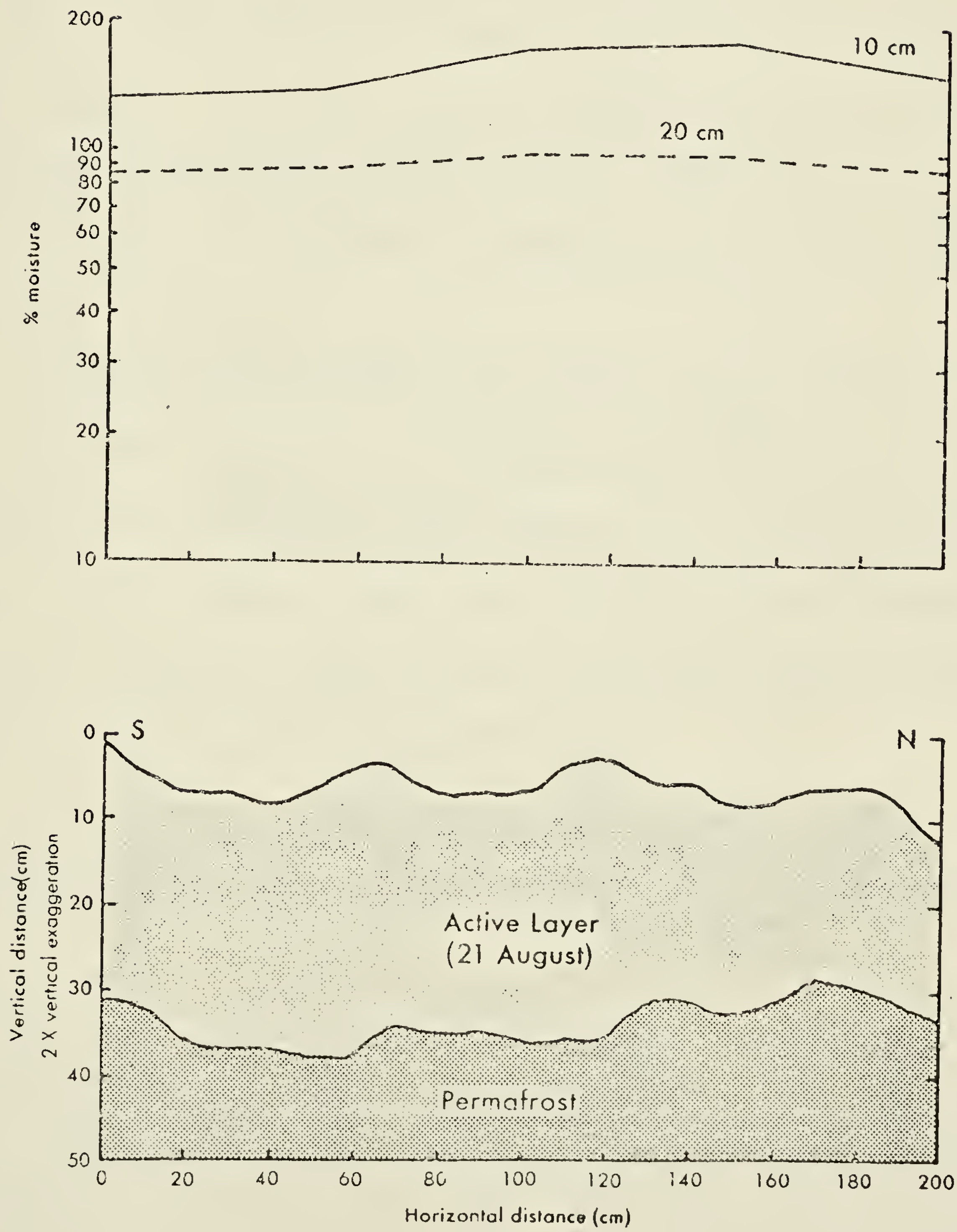


Figure 10

SOIL MOISTURE AND DEPTH OF THAW ON UNDISTURBED SITE Transect 15 b.
(soil moisture measurements taken on 21 Aug. 1973)



penetration will be less.

Along the trail, soil moisture is generally less than in the undisturbed tundra, although it varies considerably between sites (Figures 9 and 10). The greater phytomass in the birch-willow community should result in a higher transpiration rate to lower the soil moisture and allow greater thaw penetration.

The significance of organic material to the heat and moisture budgets is supported by loss-on-ignition values for representative undisturbed climax communities and in the successional birch-willow community along the trail (Figure 11).*

In the sedge tussock and sedge-heath communities, a thick insulating layer of moss and organic matter allows higher moisture retentivity and lower soil temperatures in a thinner active layer. The thin organic layer in the sedge-*Dryas* community allows the underlying mineral soil to dry quickly and thaw to a greater depth.

In the birch-willow community, organic matter is concentrated at the surface as leaf litter and decreases

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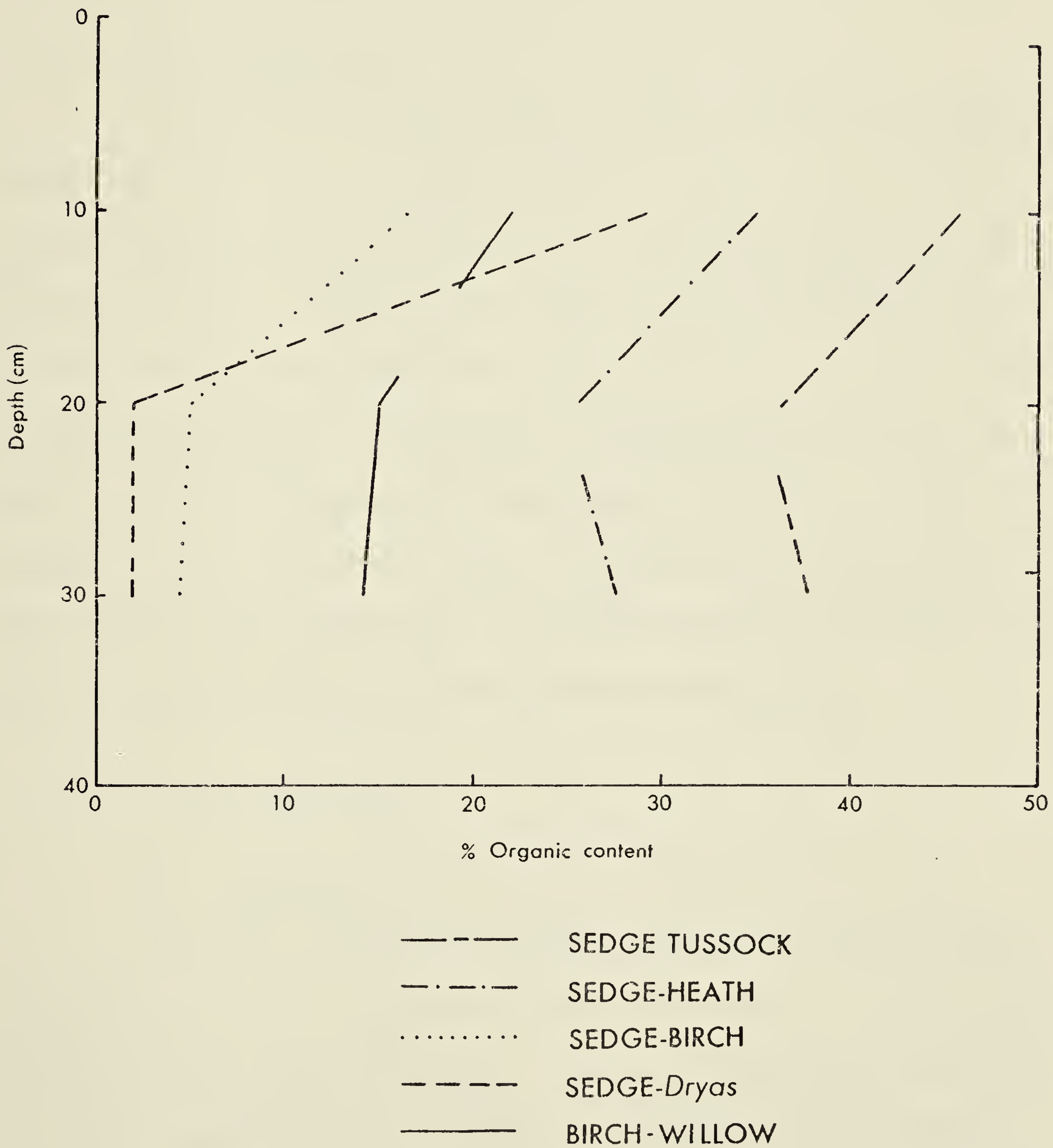
*The ash layer present at a depth of 10-25 cm is representative of a deposit occurring widely over the Yukon Territory and Alaska. The center of the volcanic eruption has been traced to the foot of Natazhat Glacier near the International border and has been dated at 1,500-1,700 B.P. (Muller 1967). In the study area, the anomalous increase of organic material below the ash layer under much of the undisturbed sedge tundra may either be a result of periglacial processes (e.g. solifluction) or possibly a remnant of an ancient soil profile which existed before the volcanic erruption.

Figure 11

ORGANIC CONTENT OF SOIL IN UNDISTURBED PLANT COMMUNITIES AND BIRCH - WILLOW ASSOCIATION*



*Missing portions of profiles represent ash layer at 10-25 cm depth

gradually with depth. Organic content of soils in the successional community is substantially less than in both the sedge tussock and sedge-heath communities but greater than in the undisturbed sedge-birch community and sedge-*Dryas* except on surface.

3.3.3.2 Soil Reaction

In the study area, soils of the undisturbed sedge tundra exhibit a pH ranging from 6.5 to 5.8 at 10 and 30 cm depths respectively (Figure 12). Following disturbance a lowering of pH is associated with the establishment of a birch-willow shrub community (6.5 to 5.1 at 10 cm). This is probably due to the greater accumulation of leaf litter which yields acid products upon decomposition. This small change in soil reaction, while ecologically unimportant to most tundra plant species, is nevertheless a further modification following revegetation of disturbed sites.

3.3.3.3 Soil Nutrients

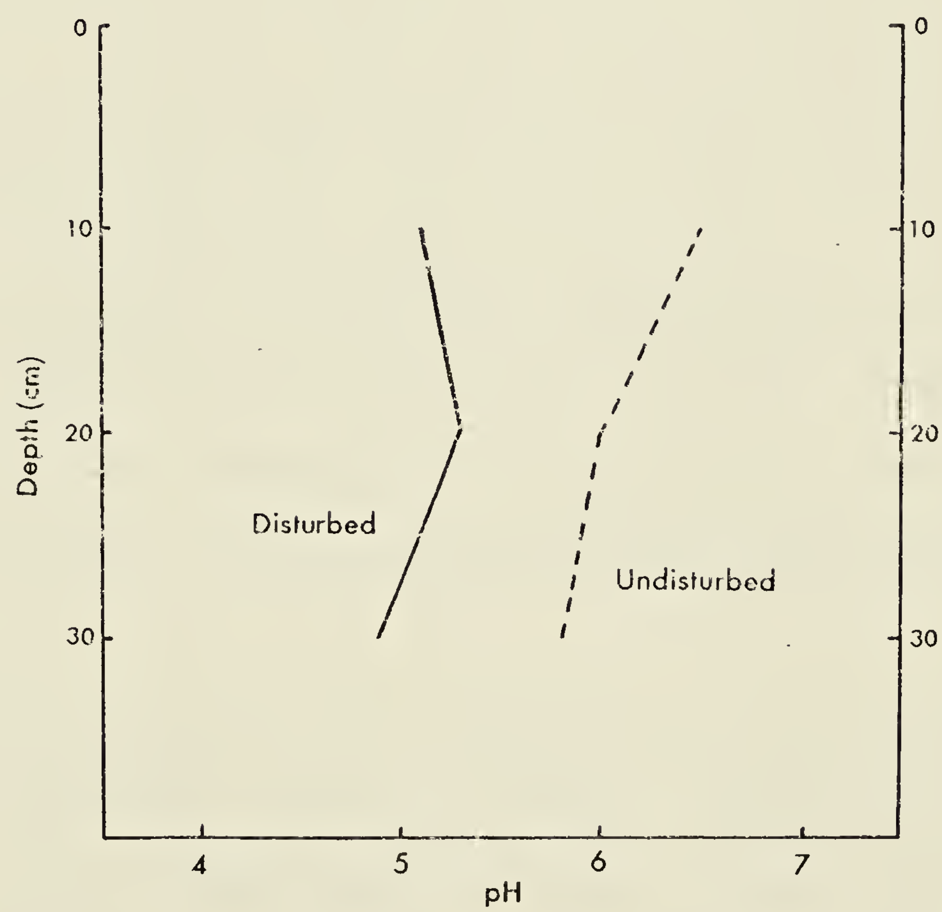
(a) Nitrogen

Nitrogen content of tundra soils is known to be especially low and may be a limiting factor in plant productivity (cf. Russell 1940). Haag (1974) suggests that low soil temperature in tundra ecosystems act to limit nitrogen production through lower decay rates and slower microbial activity.

Nitrogen content (per unit weight) of the surface

Figure 12

SOIL pH IN DISTURBED AND UNDISTURBED SITES



soils in the study area's successional shrub association is greater than that of the undisturbed climax sedge communities (Table XI). A study conducted in Alaska (Schell and Alexander 1973) has shown that legumes and other plants play a major role in the fixation of nitrogen in the alpine tundra environment. The increase of legumes (e.g. *Astragalus* and *Oxytropis*) on disturbed sites has likely had a beneficial effect on the nitrogen budget. A more favorable soil thermal regime associated with permafrost degradation could also result in accelerated microbial decomposition of the significant accumulation of leaf litter. Heilman (1966) attributes site deterioration in black spruce bogs to a thickening of the moss cover which results in a decrease of available nitrogen. Disturbance associated with periodic fires restores nitrogen in the surface layers of the soil and increases productivity. Although not directly comparable with this study, the reduction of moss cover following disturbances may have a similar effect.

Many investigators have observed the lush vegetation associated with ungulate trails and small mammal burrows (cf. Tikhomirov 1955, 1959; Danilov 1961; Skrobov and Shirovskaya 1967; Chesemore 1969; and Smirnov and Tokmakova 1971). This phenomenon in many cases is due to increased nitrification of the soil through breakdown of animal excrement. In a high arctic ecosystem, Babb (1972) noted that the available nitrogen on a muskox trail was twice that of an adjacent sedge meadow. A similar interaction is

TABLE XI

Mean (±S.E.) nutrient content of soils in undisturbed and disturbed sites (N=15)

SITES and DEPTH (cm)	N %	Ca	Mg meq/100 g.	Na	K	T.E.C.
Undisturbed						
10	0.73±0.06	24.26±6.1	6.96±0.80	0.20±0.03	0.11±0.02	55.1±7.3
20	0.40±0.03	8.15±3.0	3.19±0.26	0.17±0.01	0.10±0.01	24.2±4.8
Disturbed						
10	1.14±0.10*	19.23±4.3	2.65±0.16	0.14±0.06	0.07±0.01	50.2±8.6
20	0.48±0.04	8.81±2.7	1.31±0.11	0.13±0.02	0.05±0.01	23.8±6.0

*$p < .01$ when compared to undisturbed.

observed along the Burwash Trail. Increased use by caribou and especially small mammals has greatly augmented the available nitrogen in the upper soil horizon (Table XI).

(b) Other Nutrients

Analysis of available calcium, magnesium, sodium and potassium shows that levels of these nutrients are higher in the climax sedge tundra (Table XI) than in the successional shrub community. This may result from succession to a higher growth form (shrub) where increased nutrient uptake results in more nutrients being tied up in the vegetation. Odum (1971) has shown that climax communities have a tighter nutrient cycle than disturbed ones and few of the nutrients are lost.

CHAPTER IV

EFFECTS OF DISTURBANCE

4.1 Introduction

In the North, surface disturbances may be damaging from an aesthetic, biological or environmental point of view. There have been numerous reports documenting widespread terrain changes stemming from man's activities on the tundra, especially following the initial period of oil exploration (Hok 1969; Klein 1970a; Rickard and Deneke 1972; Hernandez 1973). However, recent technological advances have largely reduced or eliminated much of the biologically significant damage resulting from seismic operations (Bliss and Wein 1972; Kerfoot 1972a; Bliss and Peterson 1973). Current research recognizes that re-establishment of vegetation is occurring, albeit slowly in many locations, and much of the present terrain disturbance is essentially an aesthetic problem.

4.2 Effects of Disturbance on Wildlife Habitats

One of the major questions which remains largely unanswered is the effect of vegetation alteration on northern wildlife productivity. It is recognized that availability of suitable habitat is essential for the maintenance of wildlife populations. Indeed this is a major factor which determines the carrying capacity of northern and alpine

rangelands (Edwards 1954; Klein 1968, 1970b; Pegau 1968).

This chapter examines the productivity and use of habitat by wildlife along the Burwash Trail.

4.2.1 Net Annual Aboveground Production

Productive habitat is one which possesses a sufficient food source in combination with adequate cover. A measurement of net annual aboveground production was undertaken as part of the habitat study.

4.2.1.1 Methods

The clip and dry weight technique (Bliss and Wein 1974) was employed to determine net annual aboveground production at the end of the growing season in late August, 1973.

Four $1m^2$ quadrats were randomly located in both the undisturbed sedge tussock and sedge-heath communities and on the trail in the birch-willow community. In each quadrat, all current year growth of vascular plants was cut and immediately air dried. New growth of *Carex* and *Eriophorum* tussocks was distinguished by color and texture. After clipping, the usually green new growth was separated from the older brown material. For shrub species leaves and current stem elongation were collected. Current stem growth was determined from the terminal bud scars.

In the laboratory, the material was dried to a constant weight at 65-70°C and weighed to the nearest 0.1 g.

4.2.1.2 Results and Discussion

Net annual aboveground production for vascular species is considerably higher in the successional birch-willow community than in undisturbed sedge communities (Table XII). Field observations and analysis of the vegetation indicate that shrub species (*Betula glandulosa* and *Salix* spp.) as well as *Carex* and *Eriophorum* tussocks accounted for most of the increased biomass.

Carex and *Eriophorum* are food sources that are greatly favored by small mammals and caribou (Tikhomirov 1955, 1959; Kuvaev 1965; Klein 1970b; Loughery and Kelsall 1970; Smirnov and Tokmakova 1971). Certain species of *Salix* are likewise selected as browse by caribou and ptarmigan (*Lagopus* spp.) (Vakhtina 1965; Klein 1970b; Loughery and Kelsall 1970; Renewable Resources Consulting Services Limited 1971).

TABLE XII

Mean (±S.E.) net aboveground productivity in undisturbed and disturbed plant communities (N=4)

Site	Annual aboveground dry matter (g/m^2)
Undisturbed	
Sedge tussock	63.4 ± 10.0
Sedge-heath	42.5 ± 3.1
Disturbed	
Birch-Willow	143.2 ± 24.7*

*$p < .01$ when compared to undisturbed.

4.2.2 Small Mammals

4.2.2.1 Methods

Microtine densities were assessed along the trail and in the undisturbed sedge tussock tundra using the snap-trap method (after Fuller, personal communication 1973).

Three traplines, each 1 km in length, were run for 10 nights in August 1973.* One line was centered along the trail and parallel lines were run on each side of the disturbed area. The lines were placed 200 m from the trail to minimize edge effect. Each line consisted of 41 stations with 2 traps per station. Stations were spaced at 25 m intervals. Traps were placed in favorable locations such as between tussocks and under birch and willow clumps** (Plate 12). "Museum special" traps were baited with peanut butter and checked daily. There was a total of 1230 trap nights; 410 on disturbed sites and 820 on undisturbed sites.

Preliminary identification of species was made in the field. Confirmation of field specimens was made at the Department of Zoology, The University of Alberta.

4.2.2.2 Results and Discussion

It is apparent from the trapping data (Table XIII)

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*Trapping was carried out on 10-11 and 17-24 August (inclusive.) A heavy snowfall prevented trapping during the intervening period.

**Composition of the vegetation is given in Table VII.

Plate 12. Microtine trapping station around *Carex bigelowii* tussocks on the trail. *Microtus oeconomus* is shown in 'Museum Special' trap. Low shrubs in centre-left are *Salix glauca*.

that microtine populations are much higher along the trail than in the undisturbed sedge tussock tundra. Field observations of microtine activity also supported this finding.

The birch-willow community provides an ideal habitat for small mammals. The dense and tall growth of sedge tussocks along the trail affords an abundant food source and superior cover. Microtines are known to seek out the succulent green shoots and buds of *Carex* and *Eriophorum* and use the plant material for building winter nests.

As early as 1956 Pruitt (1970) observed that *Microtus oeconomus* was colonizing ruts along tractor trails on the North Slope of Alaska. In the study area the diverse microtopography and thicker active layer also create favorable microsites for small mammals. The larger tussocks are used as denning locations and runways often extend through tussocks and under thick birch and willow litter (Plate 13). A dense shrub cover and irregular terrain also create a favorable subnivean environment (Section 5.3.2).

Trapping results indicate that the distribution of boreal red-backed voles (*Clethrionomys rutilus*) centers along the shrub stands of the trail. This species is common to protected forested regions below timberline and south of the treeline but it normally does not inhabit exposed tundra areas. This small population illustrates that the tundra bioclimate along the Burwash Trail is sufficiently ameliorated for colonization by a boreal forest species.

TABLE XIII

Results of snap-trapping during August, 1973,

Burwash Uplands Yukon

(TN = trap-nights)

	TN	Total Catch	C/100 TN
Disturbed			
Microtus oeconomus	410	29	7.07
Clethrionomys rutilus	410	6	1.46
Sorex cinereus	410	5	1.22
Undisturbed			
Microtus oeconomus	820	7	0.85
Clethrionomys rutilus	820	0	0.00
Sorex cinereus	820	2	0.24

Plate 13. Microtine 'runway' through dense growth of sedge tussocks along Burwash Trail. The thick vegetation provides an abundant food source while tussocks make favorable denning sites.

While certain physical and biological changes have had a beneficial effect on microtine habitat, so too their activities will modify their environment. The effect of microtines on plant community composition and productivity remain largely unknown. Smirnov and Tokmakova (1971) have demonstrated that moderate feeding activity by tundra voles (*Microtus oeconomus*) stimulates *Carex* and *Eriophorum* shoot production and productivity. The higher levels of nitrogen in the upper soil horizons of disturbed sites (Section 3.3.3.3a, Table XI) can be partially attributed to organic breakdown of microtine excrement. Similar observations (Tikhomirov 1955, 1959) suggested that summer den excavation by voles and lemmings improves soil structure and aeration. This increases soil micro-organism populations which break down nitrogen from excrement into usable nitrates.

4.2.3 Ptarmigan

4.2.3.1 Methods

Field observations were conducted along the trail during summer 1973 and in April 1974. Food preferences were indicated through examination of browsed plants.

4.2.3.2 Results and Discussion

Willow ptarmigan (*Lagopus lagopus*) are present in the study area during the summer months (Plate 14). Willow ptarmigan thrive on a wide variety of vascular species and certain mosses. *Salix* and *Dryas* are actively sought, especially

in the early summer when they have the highest nutritive value (Tikhomirov 1959).

In the study area, field observations and examination of disturbed plant foliage showed that *Salix reticulata* is the most extensively browsed willow during the early summer. Willow ptarmigan were seldom observed in the open sedge tundra but were frequent in dense shrub stands along streams and at timberline.

Birch-willow stands along the trail provide suitable cover which is especially important during the breeding season. In late June 1973, 9 nesting hens were noted under willow clumps along a 5 km stretch of the trail. A thick cover of willow and the abundant and diverse herbaceous vegetation create productive habitat for young ptarmigan.

Populations of rock ptarmigan (*Lagopus mutus*) are widespread on the Burwash Uplands. During the summer months they are frequently observed at higher elevations but only occasionally in the sedge tundra at lower elevations. During winter, however, the birch-willow stands along the trail are used extensively for feeding and cover (Chapter V).

4.2.4 Caribou

4.2.4.1 Introduction

Much controversy surrounds the effects of seismic lines and roads on caribou populations (Klein 1970b; Calef and Lortie 1971; Hurd 1971; Weeden and Klein 1971; Macpherson

Plate 14. Willow ptarmigan (*Lagopus lagopus*) utilize the abundant growth of willow along the trail (especially *Salix reticulata*) during the summer months (9 July 1973).

et al. 1972). Three critical areas of concern are the effects of such disturbances on: 1) vegetation and habitat alteration, 2) influence on migration patterns and 3) behavioral response to man's activities.

In the study area there is a herd of approximately 100 caribou which range over the mountainous terrain surrounding the Burwash Uplands. There are two distinctions between this local race of caribou* and the barren ground caribou (*Rangifer tarandus groenlandicus*). First, they are basically non-migratory in the sense that there is no mass spring and fall movement. They are highly nomadic however, and wander in small bands or singly, except during the post-calving aggregation in mid-summer. Secondly, lichens cannot constitute an important food source at any time of the year because of their scarcity.

The aim of this portion of the study is to examine the effect of habitat alterations on caribou movements and feeding ecology and to determine the degree to which birch-willow stands along the trail are being used as a food source.

4.2.4.2 Methods

Caribou feeding selection and intensity along the trail was determined through field observations and browse counts in shrub stands during 14-20 August, 1973.

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*Their taxonomy is in doubt (Section 1.3).

The mean height and number of browsed leaves was recorded for each willow species through intensive sampling covering a 3000 m^2 area of trail.

4.2.4.3 Results and Discussion

Field observations indicated that use of the Burwash Uplands by caribou is greatest during late spring-early summer and late summer-early fall.

In late May to early June small groups of caribou move onto the Uplands from the wooded valleys. At that time there is some foraging of vegetation along the trail. Observations indicate that willow buds, new leaves, and terminal shoots are preferred as a food source during the time prior to herbaceous growth. By mid-June caribou turn to the new growth of *Carex* and *Eriophorum* in the sedge tundra. Gradually the caribou move to higher elevations to escape midsummer heat and insects and to take advantage of the phenologic change in plant development.* During midsummer few caribou use the Burwash Uplands, but in late summer caribou respond to cooler temperatures and inclement weather by moving to lower elevations (Oosenburg, personal communication, 1974). For example, during 12-14 August 1973, a heavy snowfall was followed by the movement of small groups of caribou down to the Uplands. During that period and

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*On 1 August 1973 aerial reconnaissance located a group of 80-100 caribou on Amphitheatre Mountain at an elevation of 1900 m. This is adjacent to the Burwash Uplands.

immediately following the rapid snowmelt one band of approximately 25 caribou followed the trail while browsing on willows (Plates 15, 16).

After this browsing activity a sampling program was established to determine browse preference and intensity (Table XIV). The results indicate that *Salix pulchra* is clearly preferred as browse while *Salix glauca* is the only other willow utilized. It was noted that caribou browse the tallest willows in a stand (75-110 cm).

4.3 Summary

It is evident from observations and habitat analysis that minor disturbances along the Burwash Trail have had a beneficial effect on certain wildlife populations. Especially significant is the expansion of small mammal populations on disturbed sites. Caribou are not adversely affected by the disturbance and in fact utilize the lush growth of willows along the trail. The greater phytomass of the shrub community ensures a more abundant food supply while the dense vegetation cover and highly irregular terrain provides, for some species, protection from predators. Furthermore, the much higher species diversity (Table VII) in the birch-willow community offers a greater number of species in the early growth stages when plants have the highest nutritive value.

Continued use of the long abandoned trail by caribou and other animals ensures a continuing disturbance which helps to maintain the vegetation in a disclimax stage of succession.

Plate 15. Caribou (*Rangifer tarandus*) maintain degradation along the trail by trampling while browsing willows (18 August 1973).

Plate 16. Extensively browsed *Salix pulchra* along the trail. Note how caribou have selected the leaves without taking the woody portions of the plant (18 August 1973).

TABLE XIV

Selection and intensity of browsing by caribou along the Burwash Trail during 14-20 August, 1973*

Species	Mean (± S.E.) Height of Species (cm)	Total Number of browsed willows	Mean (± S.E.) number of leaves eaten (per bush)	Total Number of leaves eaten (3,000 m^2)
Salix pulchra	110 ± 13.1	20	57.8 ± 8.1	1155
S. glauca	75 ± 6.4	4	20.0 ± 3.5	100
S. arbusculoides	35 ± 2.9	0	0.0	0
S. barrattiana	20 ± 2.2	0	0.0	0

*Total area sampled was 3,000 m^2.

CHAPTER V

WINTER ECOLOGY

5.1 Introduction

There is no published research on the effects of secondary succession in tundra ecosystems on snow distribution. While seismic lines and roads cover only a relatively small area of arctic North America,* it is not known what effect vegetation alteration in disturbed areas may have on snow distribution and ultimately on the winter life of animals and overwintering birds.

Tundra snow is distinguished by its high density and irregular distribution by wind. The wind re-distributes the snow into depressions and in the lee of protruding vegetation; it is blown free on exposed and sparsely vegetated sites. This basic inequality of the tundra snowpack (depth and density) has a profound influence on the selection of habitats by animal populations (Pruitt 1970). An adequate snow cover is especially important to the winter survival of small mammals and may be an important factor in the regulation of population fluctuations (cf. Fuller *et al.* 1969).

The intent of this chapter is to examine snow cover

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*Hernandez (1972) calculated that terrain disturbances resulting from oil exploration in the intensively surveyed portion of Tuktoyaktuk Peninsula (2100 km^2) cover 0.52% of the area.

on disturbed sites and how it influences the quality of winter habitats.

5.2 Methods

A Mount Rose Snow Sampler was used to determine snow depth and water equivalency on transects across disturbed sites and randomly in the adjacent undisturbed tundra.

Measurements of subnivean and ambient air temperatures were carried out on the trail on 6 April 1974 by means of a YSI Telethermometer. Readings were taken at 5 cm intervals.

Field observations and random browse counts were used to assess the extent to which ptarmigan utilize winter habitats along the trail.

5.3 Results and Discussion

5.3.1 Snow Distribution

The winter climate of the study area is noted for its low precipitation and frequent high winds. During April the open sedge tundra on the Burwash Uplands had a snow cover which varied from 10-30 cm. However in depressions and small stream valleys snow is re-deposited into large drifts, similar to the 'zabois' described by Russian authors (cf. Formozov 1946).

Shrub stands along the trail act in much the same way to catch and re-deposit the blowing snow (Plates 17, 18). Random measurements showed that snow accumulation was 100-400%

Plate 17. Snow is blown from the exposed sedge tundra and deposited in shrub stands and thermokarst depressions along the trail (6 April 1974).

Plate 18. Snow deposition in thermokarst depression to the lee of a willow clump. Snow to left is typical of snow cover on undisturbed tundra. Stick is 1 m in length (6 April 1974).

higher in the birch-willow community than in the sedge tundra. Figure 13 shows the great increase in snow depth and water equivalency in a representative transect from the undisturbed sedge-heath community through a birch-willow stand on the trail.

5.3.2 Ecological Implications

Snow conditions in the disturbed area play an important role in the survival of microtime population during the winter months. Figure 14 illustrates the insulating qualities of a thick snow cover. On 6 April 1974 the temperature of the snow-air interface was -15° C while the temperature at the moss surface was -5° C. Heat radiating from the ground and surrounding vegetation results in a well developed 'pukak' layer (depth hoar) (Pruitt 1970) just above the moss surface (Plate 19). The dense shrub growth provides an excellent subnivean environment by creating many macronivean spaces which are used by microtines.

Rock ptarmigan extensively browse the winter buds and terminal twigs of willow protruding above the snow (Plate 20). Random browse counts showed that in some areas rock ptarmigan consumed 15% of the annual growth. *Salix glauca* is preferred, although other willow species are also used. *Betula glandulosa* is not browsed to any extent. Snow burrows were noted in the thicker birch-willow stands; the deeper less dense snow cover along the trail provides protection against the cold and predators.

Figure 13

SNOW DEPTH AND WATER EQUIVALENCY ACROSS BURWASH TRAIL ON 6 April 1974

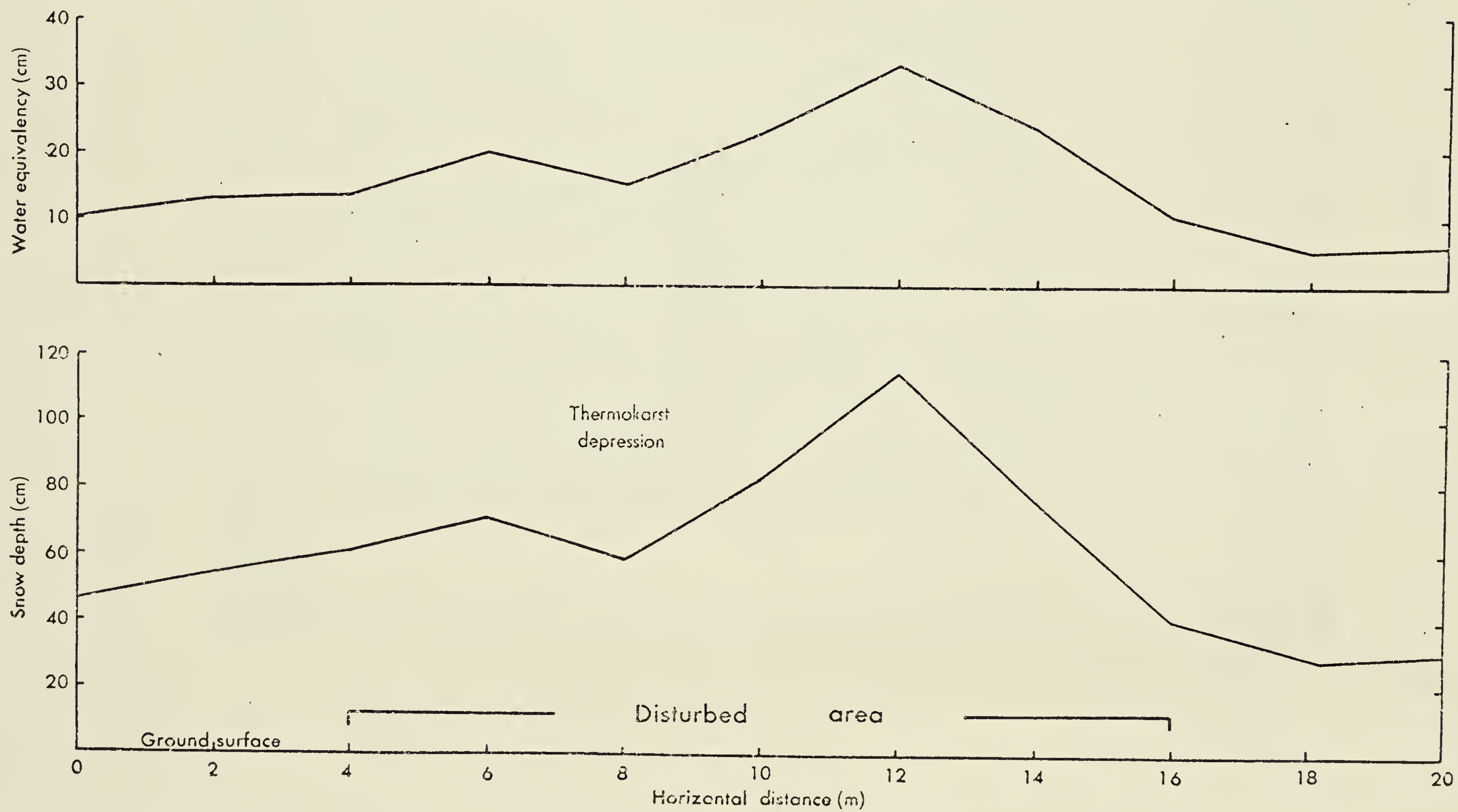

Figure 14

VERTICAL TEMPERATURE PROFILE THROUGH A SNOW DRIFT IN BIRCH-WILLOW COMMUNITY ALONG THE BURWASH TRAIL
(Temperature profile measured with YSI Telethermometer on 6 April 1974)

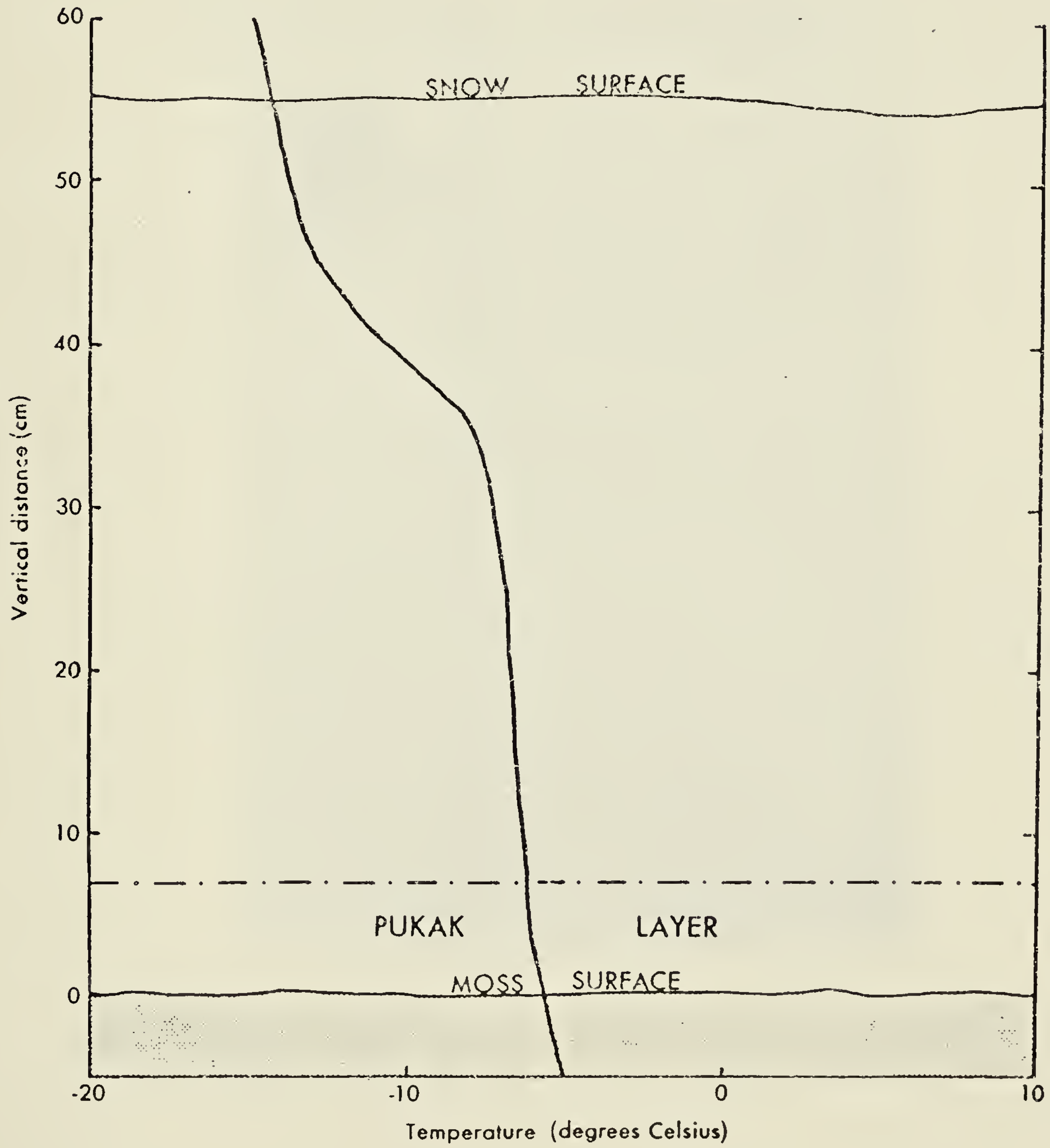

Plate 19. YSI Telethermometer was used to record temperatures through snow drift on the trail. Notice well developed 'pukak' layer (6 April 1974).

Plate 20. Rock ptarmigan (*Lagopus mutus*) browse *Salix glauca* protruding above the snow. Note snow drifts in dense willow thickets along the trail in background. Such snow provides favorable locations for burrows (7 April 1974).

Although willow ptarmigan utilize this area during summer they overwinter in protected stream valleys at lower elevations. For example during April 1974 large numbers of willow ptarmigan were observed in riparian willow thickets along upper Burwash Creek.

There was little evidence of caribou use of the trail during winter. This is not surprising in view of the deep snow cover along the trail which would hinder movement.

5.4 Summary

Secondary succession to a shrub community causes the accumulation of a significantly greater snow cover along Burwash Trail than in the climax sedge tundra. This in turn modifies the subnivean environment which creates a favorable winter habitat for the increased microtine population along the trail.

Protruding willow buds and twigs are browsed by overwintering rock ptarmigan, while suitable snow conditions provide sites for snow burrows.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study has examined the long-term ecological consequences of terrain disturbances in the alpine tundra environment of the Burwash Uplands, southwest Yukon Territory. It has shown that disturbance of the organic layer above ice-rich permafrost, initially through foot and wagon traffic and now similarly by animals, has caused degradation of permafrost largely in the form of thermokarst subsidence. This is strikingly evident through accentuation of the microtopography along the path of the disturbance. Prominent consequences of microtopographic alteration have been the development of an extensive myriad of ruts and an increase in both density and size of sedge tussocks, primarily *Carex bigelowii* and *Eriophorum vaginatum*. There is little evidence of fluvial erosion even where the trail crosses small stream valleys.

Along the trail, allogenically induced secondary succession has caused the replacement of the climax sedge association by a birch-willow association. On disturbed sites, the vegetation is characterized by a high cover-abundance of shrub species and a significantly more diverse herbaceous flora. Species richness is fostered by the wide range of site conditions associated with the irregular microtopography and a deeper active layer.

Degradation of the permafrost, linked with the establishment of a shrub community, has further modified soil conditions in the study area. Soil moisture is dependent on microtopography and plant cover with its accompanying organic buildup; thus on disturbed sites moist thermokarst depressions typically have a thinner active layer than surrounding drier hummocks. On undisturbed sites, a thick organic layer and less microrelief result in higher and more uniform soil moisture values and consequently, a shallower and more homogeneous frost table. Soil organic content is correlated with vegetation type and successional stage. Along the trail, birch-willow stands concentrate organic material near the surface as leaf litter. In the undisturbed climax sedge tundra organic content of the soils is generally greater than in the successional birch-willow community. The soil pH has been altered from 6.5 (at 10 cm) of the original sedge tundra to 5.1 following the establishment of a birch-willow community. In the study area's successional shrub association the higher nitrogen content of the surface soils is primarily due to nitrogen-fixing organisms associated with the increase in legumes such as *Astragalus* and *Oxytropis* as well as increased nitrification by concentrations of excrement from caribou and small mammals.

The ameliorated bioclimate and favorable vegetation changes have benefited certain wildlife populations in the study area. Small mammals have successfully colonized the disturbed area and use the lush growth of sedges for food

and nesting material. A thick cover of shrubs and the abundant and diverse herbaceous vegetation are sought by nesting willow ptarmigan. Caribou are not adversely affected by the disturbance and in fact browse willow stands at certain times of the year. Plant-animal interactions stimulate plant productivity through a continuing disturbance that probably interrupts the successional sequence.

A more irregular terrain and increased biomass enables the accumulation of a deeper snow cover which provides favorable winter habitat for small mammals and overwintering birds.

Although the media have successfully painted a picture of widespread destruction associated with man's activities in the North, there has been little documentation of the long-term effects of seismic lines and similar trail making activities in tundra terrain. So also has the distinction between aesthetic and environmental harm escaped adequate recognition.

It has long been recognized that change is characteristic of all ecosystems even in relativelv steadv-state communities (Churchill and Hanson 1958). For example, we know that changes such as those induced by forest fires and flooding are natural mechanisms which induce the development of varied communities that are essential to the maintenance of high ecological productivity. One of the major problems in assessing the consequences of tundra disturbances is in distinguishing between non-damaging and deleterious terrain changes. This study has emphasized that although man-induced

disturbances have undoubtedly altered the ecological balance of an alpine ecosystem, they have been beneficial from the biological standpoint of increased plant and animal productivity. Thus, it is felt that there is a need to reassess the generally negative attitude toward perturbation in northern environments.

In conclusion, this study of a long abandoned tundra disturbance can be used to predict the effects of more recent similar disturbances in the North American arctic and alpine tundra.

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APPENDIX I

A. DEPTH OF THAW ON DISTURBED SITES

Sample Plot Number	Date	Mean (± S.E.)	Maximum	Minimum	Standard Deviation	Coeff. of Variation
1	June 30	22.7 ± 1.2	31.0	16.0	4.95	.22
	July 17	36.2 ± 1.5	45.0	24.0	6.75	.19
	August 07	45.2 ± 1.9	70.0	30.0	8.72	.19
	August 21	50.1 ± 2.5	81.0	30.0	11.45	.23
2	June 30	14.3 ± 0.7	20.0	8.0	3.06	.21
	July 17	25.1 ± 0.8	32.0	16.0	3.87	.15
	August 07	33.0 ± 1.2	40.0	19.0	5.36	.16
	August 21	36.2 ± 1.2	43.0	21.0	5.67	.16
3	June 30	20.8 ± 1.6	33.0	10.0	7.54	.36
	July 17	29.5 ± 0.8	32.0	16.0	3.87	.19
	August 07	40.1 ± 1.9	52.0	20.0	8.74	.22
	August 21	44.1 ± 2.1	56.0	22.0	9.44	.21
4	June 30	26.2 ± 2.5	44.0	10.0	11.47	.44
	July 17	35.5 ± 3.1	52.0	11.0	14.29	.40
	August 07	44.6 ± 2.9	66.0	23.0	13.52	.30
	August 21	47.7 ± 3.1	70.0	24.0	14.16	.30
5	June 30	19.5 ± 1.3	30.0	10.0	6.02	.31
	July 17	31.8 ± 1.8	45.0	20.0	8.23	.26
	August 07	39.7 ± 2.9	66.0	22.0	13.25	.30
	August 21	43.7 ± 3.4	70.0	24.0	15.37	.35
6	June 30	17.0 ± 0.7	21.0	12.0	3.09	.18
	July 17	21.0 ± 0.6	27.0	18.0	2.93	.13
	August 07	36.3 ± 1.0	45.0	26.0	4.56	.18
	August 21	39.8 ± 1.0	48.0	28.0	4.68	.12
7	June 30	14.7 ± 1.2	27.0	8.0	4.96	.34
	July 17	25.0 ± 1.2	37.0	16.0	5.63	.23
	August 07	40.7 ± 1.6	55.0	29.0	7.52	.18
	August 21	44.8 ± 1.7	58.0	35.0	7.77	.17
8	June 30	22.9 ± 0.8	32.0	17.0	3.51	.15
	July 17	36.2 ± 1.3	48.0	28.0	6.06	.17
	August 07	49.9 ± 1.6	65.0	39.0	7.12	.14
	August 21	56.1 ± 1.6	72.0	49.0	7.42	.13
9	June 30	12.0 ± 0.9	21.0	6.0	4.04	.34
	July 17	20.0 ± 2.3	34.0	10.0	7.55	.38
	August 07	27.8 ± 2.3	47.0	14.0	10.63	.39
	August 21	31.2 ± 2.4	54.0	20.0	11.05	.36
10	June 30	23.4 ± 0.9	30.0	15.0	4.34	.19
	July 17	34.9 ± 0.7	39.0	24.0	3.31	.09
	August 07	52.5 ± 1.8	62.0	30.0	8.23	.16
	August 21	56.1 ± 1.8	65.0	30.0	8.33	.15
11	June 30	16.3 ± 0.8	23.0	9.0	3.47	.21
	July 17	27.4 ± 1.0	37.0	16.0	4.62	.17
	August 07	35.8 ± 1.1	45.0	28.0	4.86	.14
	August 21	40.7 ± 1.1	47.0	29.0	4.89	.12
12	June 30	21.0 ± 1.8	34.0	10.0	8.16	.39
	July 17	27.9 ± 1.7	43.0	18.0	7.81	.28
	August 07	38.8 ± 1.4	51.0	32.0	6.41	.17
	August 21	43.3 ± 1.1	53.0	37.0	5.23	.12
13	June 30	17.4 ± 2.2	36.0	5.0	10.15	.58
	July 17	26.1 ± 2.2	42.0	12.0	10.02	.38
	August 07	44.5 ± 1.6	56.0	34.0	7.53	.17
	August 21	48.1 ± 1.8	60.0	36.0	8.04	.17
14	June 30	15.1 ± 1.0	24.0	8.0	4.60	.30
	July 17	26.0 ± 1.1	35.0	16.0	5.08	.20
	August 07	35.1 ± 1.0	42.0	28.0	4.59	.13
	August 21	39.6 ± 1.1	47.0	30.0	4.86	.12
15	June 30	25.6 ± 1.8	35.0	9.0	8.47	.33
	July 17	39.0 ± 1.3	46.0	25.0	5.85	.15
	August 07	50.0 ± 1.1	57.0	42.0	5.00	.10
	August 21	52.7 ± 1.1	60.0	43.0	5.13	.10

APPENDIX I (continued)

B. DEPTH OF THAW ON UNDISTURBED SITES

Sample Plot Number	Date	Mean (± S.E.)	Maximum	Minimum	Standard Deviation	Coeff. of Variation
1	June 30	24.6 ± 1.1	37.0	15.0	5.00	.20
	July 17	37.7 ± 1.1	46.0	28.0	5.20	.12
	August 07	46.8 ± 0.9	56.0	40.0	4.14	.09
	August 21	51.6 ± 0.9	61.0	46.0	4.00	.08
2	June 30	17.1 ± 1.1	22.0	13.0	2.37	.14
	July 17	29.0 ± 0.6	33.0	24.0	2.75	.10
	August 07	36.6 ± 0.4	40.0	32.0	1.88	.05
	August 21	39.0 ± 0.5	43.0	35.0	2.09	.05
3	June 30	15.0 ± 0.6	21.0	9.0	2.92	.20
	July 17	23.6 ± 0.7	28.0	17.0	3.11	.13
	August 07	33.9 ± 0.8	39.0	28.0	3.48	.10
	August 21	36.3 ± 0.8	42.0	30.0	3.58	.10
4	June 30	20.0 ± 0.4	23.0	15.0	2.03	.10
	July 17	24.6 ± 0.3	27.0	21.0	1.56	.06
	August 07	33.4 ± 0.4	36.0	30.0	1.88	.06
	August 21	35.9 ± 0.5	40.0	32.0	2.07	.06
5	June 30	13.4 ± 0.5	19.0	10.0	2.20	.16
	July 17	19.2 ± 0.7	25.0	15.0	3.42	.18
	August 07	34.6 ± 1.2	36.0	27.0	5.32	.15
	August 21	38.6 ± 1.5	55.0	30.0	6.93	.18
6	June 30	20.2 ± 1.2	30.0	7.0	5.40	.27
	July 17	26.9 ± 0.9	31.0	17.0	3.90	.14
	August 07	34.8 ± 0.5	39.0	30.0	2.29	.07
	August 21	36.3 ± 0.5	41.0	32.0	2.52	.07
7	June 30	20.5 ± 0.7	26.0	13.0	3.30	.16
	July 17	26.5 ± 0.7	32.0	22.0	3.19	.12
	August 07	34.8 ± 0.6	42.0	30.0	2.84	.08
	August 21	36.3 ± 0.5	43.0	33.0	2.52	.07
8	June 30	16.3 ± 0.8	21.0	8.0	3.56	.23
	July 17	26.1 ± 0.7	29.0	17.0	3.30	.14
	August 07	38.3 ± 0.9	40.0	27.0	4.09	.12
	August 21	40.9 ± 0.9	43.0	28.0	4.19	.12
9	June 30	16.3 ± 0.5	20.0	12.0	2.29	.14
	July 17	26.1 ± 1.2	34.0	19.0	5.48	.21
	August 07	38.3 ± 1.1	47.0	30.0	5.18	.14
	August 21	40.9 ± 1.3	54.0	34.0	5.80	.14
10	June 30	19.4 ± 1.3	28.0	8.0	5.92	.31
	July 17	28.9 ± 1.3	35.0	17.0	5.88	.20
	August 07	38.8 ± 0.6	44.0	34.0	2.61	.07
	August 21	40.7 ± 0.7	48.0	35.0	3.38	.08
11	June 30	15.5 ± 0.3	18.0	13.0	1.21	.08
	July 17	28.7 ± 0.6	35.0	24.0	2.78	.10
	August 07	33.0 ± 0.4	37.0	31.0	1.96	.06
	August 21	34.3 ± 0.4	37.0	31.0	2.05	.06
12	June 30	15.4 ± 0.5	20.0	12.0	2.14	.14
	July 17	32.5 ± 0.6	25.0	16.0	2.91	.14
	August 07	33.8 ± 0.7	40.0	30.0	3.39	.10
	August 21	36.7 ± 0.7	42.0	32.0	3.23	.09
13	June 30	15.3 ± 0.6	21.0	11.0	2.89	.19
	July 17	22.4 ± 0.8	30.0	18.0	3.88	.17
	August 07	35.5 ± 1.2	50.0	30.0	5.45	.15
	August 21	37.2 ± 1.3	54.0	32.0	6.00	.16
14	June 30	11.5 ± 0.7	19.0	8.0	3.22	.28
	July 17	18.5 ± 0.6	24.0	14.0	2.94	.16
	August 07	33.1 ± 0.5	37.0	28.0	2.50	.08
	August 21	38.0 ± 0.7	46.0	33.0	3.37	.09
15	June 30	12.8 ± 0.5	17.0	9.0	2.49	.19
	July 17	19.1 ± 0.7	24.0	14.0	3.02	.16
	August 07	25.7 ± 0.7	31.0	20.0	3.14	.12
	August 21	28.5 ± 0.9	36.0	22.0	3.90	.14

APPENDIX II

SYSTEMATIC TABULATION OF PLANT SPECIES

VASCULAR PLANTS

GRAMINEAE

Arctagrostis arundinacea (Trin.) Beal.
Festuca altaica Trin.

CYPERACEAE

Carex atrofusca Schk.
Carex aquatilis Wahl.
Carex bigelowii Torr.
Carex membranacea Hook.
Eriophorum angustifolium Honckn.
Eriophorum brachyantherum Trautv. and Mey.
Eriophorum vaginatum Tausch.

LILIACEAE

Tofieldia pusilla

SALICACEAE

Salix arbusculoides Anders.
Salix barrattiana Hook.
Salix glauca L.
Salix pulchra Cham.
Salix reticulata L.

BETULACEAE

Betula glandulosa Michx.

POLYGONACEAE

Polygonum bistorta Hult.
Polygonum viviparum L.

CARYOPHYLLACEAE

Stellaria monantha Hult.
Silene acaulis L..

RANUNCULACEAE

Aconitum delphinifolium DC.
Anemone narcissiflora L.
Anemone parviflora Michx.

PAPAVERACEAE

Papaver lapponicum (Tolm.) Nordh.

CRUCIFERAE

Cardimine sp.
Eutrema edwardsii R. Br.
Parrya nudicaulis (L.) Regel

SAXIFRAGACEAE

Parnassia palustris L. var. *neogaea* Fern.
Saxifraga hirculus L.
Saxifraga hieracifolia Waldstr. & Kit.

ROSACEAE

Dryas integrifolia Vahl.
Dryas octopetala L.
Potentilla diversifolia Lehm.
Potentilla fruticosa L.
Rubus chamaemorus L.

LEGUMINOSAE

Astragalus umbellatus Bunge
Lupinus arcticus S. Wats.
Oxytropis maydelliana Trautv.

EMPETRACEAE

Empetrum nigrum L.

PYROLACEAE

Pyrola grandiflora Rad.

ERICACEAE

Arctostaphylos rubra (Rehd. & Wils.) Fern.
Cassiope tetragona (L.) D.Don
Ledum palustre Oed.
Vaccinium uliginosum L.
Vaccinium vitis-idaea L.

GENTIANACEAE

Gentiana algida Pall.
Gentiana prostrata Haenke
Gentiana propinqua Richards

POLEMONIACEAE

Polemonium acutiflorum Willd.

BORAGINACEAE

Mertensia paniculata (Ait.) G. Don

SCROPHULARIACEAE

Pedicularis arctica R. Br.
Pedicularis capitata Adams
Pedicularis labradorica Wirsing
Pedicularis lanata Cham. & Schlecht.
Pedicularis oederi M. Vahl.
Pedicularis sudetica Willd.

VALERIANACEAE

Valeriana capitata Pall.

COMPOSITAE

Petasites frigidus (L.) Fries
Saussurea angustifolia DC
Senecio atropurpureus (Ledeb.) Fedtsch.
Senecio lugens Richards.
Senecio resedifolius Less.
Solidago multiradiata Ait.

BRYOPHYTES

DICRANACEAE

Dicranum elongatum (Schleich ex Schwaegr.)

BRYACEAE

Leptobryum pyriforme (Hedw.) Wils.

AULACOMNIACEAE

Aulacomnium palustre (Hedw.) Schwaegr.

THUIDIACEAE

Thuidium abietinum (Hedw.) B.S.G.

RHYTIDIACEAE

Rhytidium rugosum (Hedw.) Kindb.

POLYTRICHACEAE

Polytrichum strictum Brid.

FUNGI

AGARICACEAE

Cortinarius sp.

LICHENS

CLADONIACEAE

Cladonia pyxidata (L.) Hoffn.
Cladonia fimbriata (L.) Fr.
Cladonia sp.

STEREOCAULACEAE

Stereocaulon alpinum Laur.

PARMELIACEAE

Cetraria cucullata (Bell.) Ach.

USNEACEAE

Thamnolia vermicularis (SW.) Ach. ex Schaer.

PHYSCIACEAE

Physconia muscigena (Ach.) Poelt.